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Editorial

PRESIDENTIAL ADDRESS

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TWELVE years ago a group of surgeons throughout this country, realizing that approximately 40 to 50 per cent of all admissions to the surgical services of our large metropolitan hospitals were the result of trauma, believed there was need of a forum to study and discuss all forms of injury. That there was such a need was substantiated by the fact that many of the surgical societies meeting throughout the country devoted less than 10 per cent of their program to trauma. As a result of this realization, this association had its birth in San Francisco in June, 1938. Now, twelve years later, we must ask ourselves several questions and attempt to answer them.

First, what were the aims and purposes established at that meeting? These were many, but primarily our object was to have a group of trained surgeons, whose primary interest was the surgery of trauma, and by integrated meetings of this group to obtain an interchange of ideas. This in turn would improve the treatment of the injured individual by disseminating this information throughout the country.

The second question we must ask ourselves is whether we have accomplished what we set out to do. We can state that a program of education has been established in the surgery of trauma. To do this we have drawn together the men best equipped to study the problem, teach the principles and accomplish this aim. Around these men we have built, during these past twelve years, an annual program. By publication in national surgical journals circulated throughout the world, these ideas and principles have exerted a constructive influence on the surgery of trauma. Our programs have attracted many non-member guests and members of the armed forces whom we have been happy to welcome to our meetings.

We were still in our infancy and hardly in good running order when World War II erupted. Many of our membership were fully equipped to step into important positions of war surgery, as consultants and chiefs of surgical sections in all branches of the armed forces, as well as advisers and consultants in a civilian capacity to the tremendous number of young surgeons who required special instruction in the surgery of trauma. Such a trained and experienced group had never before been available for any war. The record of accomplishments of these gentlemen speaks for itself.

The entire medical profession can point with pride to the tremendous advances and improvements in surgery during the recent war. The amazingly low mortality rate among the wounded is an index of the skill of the surgeons working in the field of trauma. To cite only a few examples, the entire treatment of hand surgery has been advanced, with reconstruction, transposition of fingers and flexor tendon

grafts. We can be proud that some of our members were among the pioneers in this extremely important field.

In fracture surgery with extensive loss of bone, the use of bone banks has materially shortened disability and undoubtedly saved many limbs which might otherwise have been sacrificed.

Perhaps there has been no more gratifying work done than that of the plastic surgeons with their extensive reconstructive work to rehabilitate those patients horribly disfigured.

Neurosurgery also made rapid strides with the saving of many lives and the salvaging of many extremities.

The tremendous advance in the treatment and rehabilitation of the paraplegic and amputee groups needs no comment before this organization.

Thoracic and abdominal surgery became much more extensive and at the same time less hazardous. For all these advances we must give a vast amount of credit to improvements in anesthesia and the presence of antibiotics as well as advances in surgical technic.

The tremendous amount of research and clinical work in blood and blood chemistry has been invaluable in the more difficult surgical procedures.

The lessons we learned from the war gave us further impetus to handle better our ever mounting civilian casualties resulting from this era of speedy transportation.

During the post-war readjustment period some of our members took over Veterans' Administration positions of high rank, including the medical directorship, which was placed in the able hands of Paul Magnuson, the recent past president of this organization. In fact, the entire medical program of the Veterans' Administration was blueprinted by Magnuson.

In coordination with several other national organizations, the teaching of trauma has been broadcast into every community hospital in the country. As a result of this teaching, the crossroad's physician is far better able to treat the injured when serious accidents occur.

So much for our accomplishments, although in my attempt at brevity, many have been omitted.

The third question to be asked is in what way have we failed? We have believed that a democratic organization will best serve the ideals for which we became established. Perhaps in our zeal to obtain only the very outstanding men, we have failed in obtaining a more geographic distribution, which might better fulfill our original aim of more widespread knowledge of and treatment of trauma. Again in our desire to have the nationally and internationally famous men in the field of trauma, have we not forgotten the younger man, who may not yet have attained national stature, but by whose enthusiasm as well as skill, the best interests of this organization may be furthered?

Finally, we must ask ourselves what we should do for the future. This I believe can be summarized briefly in accordance with my preceding remarks: (1) Encourage a wider geographic distribution of the membership to improve the dissemination of knowledge; (2) attempt to include in the membership, young, well trained and enthusiastic surgeons; (3) encourage the inclusion of men interested in the basic field of trauma who will initiate and stimulate much needed research, not only in the clinical but in the investigational side; (4) try constantly to improve the quality of our programs from a scientific and clinical point of view; (5) coordinate the surgery of trauma with the field of medicine as a whole, studying the special problems of trauma in the diabetic, the tubercular and many other special conditions and (6) continue the fundamentals already established by this association so that by an interchange of ideas, a continued interest in the basic principles, a constant effort to advance, an effort to spread the doctrine of right and wrong in the surgery of trauma to the crossroads, this highly important field may continue to advance as it has in the past twelve years for the better management of the injured.

Original Articles

PRIMARY ANTERIOR DISLOCATION OF THE SHOULDER*

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THE records of 573 shoulder dislocations were examined and 101 consecutive cases, which satisfied the following prerequisites, selected for study. Each was traumatic in origin, a primary lesion with anterior displacement, proved by roentgenogram and reduced, treated and subsequently followed up for six months to five years or more by the Fracture Service of the Presbyterian Hospital in New York. The results are neither authoritative nor statistically significant since the observation period often was inadequate for an end result evaluation. However, it was considered that as a preliminary study such a sample series should represent a fair cross sectional index of the clinical behavior of this lesion and the incidence and significance of certain complications. Those who find the results to their liking may say that the inadequately followed cases were asymptomatic; others may say these patients eventually had trouble and went elsewhere for help. The truth lies somewhere between these two extremes. (Table I.)

TABLE I
DURATION OF OBSERVATION

Years Followed Up	Cases
½–1	19
1–2	24
2–3	24
3–4	9
4–5	11
5 Plus	14

TREATMENT—MOBILIZATION OR IMMOBILIZATION?

Treatment programs advocated by various authors[1–4] vary only in detail and consist of the prevention of abduction and external rotation by some dressing such as a sling and swathe followed with exercises and voluntary protection until healing occurs. These protective dressings often are inaccurately spoken of as immobilization; none immobilizes but merely restricts shoulder motion.

TABLE II

Weeks of Sling and Swathe	Recurrent	Non-recurrent	
		Without Fracture	With Fracture
0–1	14	20	7
1–2	6	22	14
2–3	1	4	11
3 Plus	0	0	2

Two of the staunchest advocates of prolonged immobilization report somewhat dissimilar experiences. Watson-Jones,[5] who advises collar, cuff and swathe dressings for four weeks, was impressed that in a series of several hundred dislocations none was known to have recurred. He also decried the importance of repairing the damaged anterior joint supports in treating established recurrent lesions and contended that the success of this procedure depended more upon operative exposure of the anterior joint structures.[6] Nicola,[7] who treated primary lesions with exploration through the anterior approach followed by protection with similar dressings for a period of eight weeks, reported a recurrence rate of 12 per cent in a well documented series of cases.

The cases in this study received treatment as outlined in Tables II, III and IV.

* From the Department of Orthopedic Surgery, College of Physicians and Surgeons, Columbia University, and the Fracture Service of the Presbyterian Hospital, New York, N. Y.

It is noted in Table II that although eighty-three patients wore protective dressings for less than two weeks only twenty had recurrence of their dislocations. It should be stated that all patients were required to wear a protective dressing while sleeping for at least four weeks.

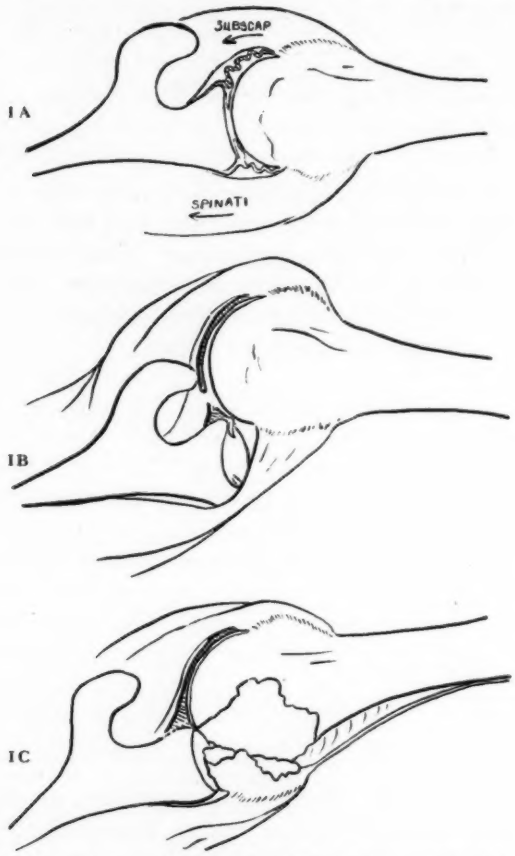


FIG. 1. Traumatic anterior dislocation usually follows rupture, avulsion or splitting of the anterior (B) or posterior (C) supports of the joint. Both may be damaged simultaneously but normally disruption of one tends to spare the other.

Table III discloses that all twenty-one recurrent cases received early mobilization, at least to the extent of gravity-free pendulum exercises. Before condemning early motion as the cause of recurrence, it should also be noted that fifty-three other cases treated in the same manner did not recur.

Twenty-one dislocations recurred. Eleven patients suffered only one known recurrence, five taking place within six months and six between one and a half and three years after the primary episode. Ten patients suffered multiple recurrences, five beginning within one year and five between one and three years. Eighteen recurrences resulted from inadequate traumas, three followed violent injuries and one occurred within ten days as a result of faulty treatment. Excluding the last four cases the known incidence of recurrence was 17 per cent which approaches that reported by Nicola following exploration and eight weeks'

TABLE III

Week Began Pendulum Exercises	Recurrent	Non-recurrent	
		Without Fracture	With Fracture
0–1	21	33	20
1–2	0	10	10
2–3	0	2	4
3 Plus	0	1	0

TABLE IV

Overhead Motion Possible (Mo.)	Recurrent	Non-recurrent	
		Without Fracture	With Fracture
0–1	4	3	0
1–2	9	9	1
2–3	5	7	1
3 Plus	3	27*	32†

* Included 6 cases complicated by nerve lesions and 14 cases complicated by subacromial derangement.

† Included 10 cases complicated by nerve lesions and 10 cases complicated by subacromial derangement.

protection. It would appear, therefore, that prolonged protection and abolition of function may not be as important a factor in the prevention of recurrences as its advocates often contend. On the contrary, this study suggests that recurrences may depend more upon the site and nature of the primary pathologic condition, and that certain definable groups of patients and dislocations may be prone or immune to this complication.

PATHOLOGY

Traumatic anterior dislocation results from a disruption of either the antero-inferior supports of the shoulder joint (glenohumeral ligaments and capsule, Figure 1B) or the posterosuperior supports (external rotator tendons). The latter may consist of tendon

FIG. 2. Before reduction; apparently an ordinary avulsion of the greater tuberosity. After reduction; the tuberosity fracture is actually an extension of a posterior compression of the humeral head; this dislocation recurred.

rupture but is more commonly an avulsion of the greater tuberosity of the humerus. (Fig. 1C.) Both anterior and posterior supports may be damaged simultaneously, but as a general rule disruption of one tends to spare the other. Damage to either or both may be accompanied with other less important yet potentially complicating phenomena, e.g., posterior compression fracture of the humeral head, fracture of the glenoid rim or fracture or displacement of the long head of the biceps.

Consideration of lesions resulting from disruption of the posterior stabilizers of the joint (Fig. 1C) warrants the premise that recurrences need not be feared since the anterior structures are spared and the essential damage heals by bony union. Thirty-four of the cases studied were in this category as evidenced by the presence of an avulsed tuberosity fracture. None recurred. One recurrent lesion showed a fracture of the tuberosity at the time of the primary episode. However, this was not an avulsed fracture as depicted in Figure 1C but rather an extension of a posterior compression of the humeral head caused by impingement against the glenoid or acromion at the time of dislocation. (Fig. 2.)

The essential pathologic condition predisposing to recurrence following traumatic dislocation consists of damage to the anteroinferior supports of the joint aided and abetted at times by posterior compression of the humeral head. In six cases anterior support damage was present in the form of a fracture or avulsion of the glenoid rim and it was likely that a similar pathologic condition passed unrecognized in other cases. In all recognized lesions of this type healing was by bony union and no recurrences ensued. Sixty-seven cases showed no evidence of any fracture accompanying the primary dislocation and must, therefore, have incurred the essential injury to either the glenohumeral ligaments or the tendon cuff. Table V suggests that in these cases it may become possible to differentiate the site of the main pathologic condition and prognosticate the changes of recurrence with fair accuracy from the start. It discloses that about 50 per cent of all lesions without fracture became recurrent; in 90 per cent of all patients under twenty years of age there was recurrence; in 60 per cent of all patients

TABLE V

Age (yr.)	Recurrent	Non-recurrent	
		Without Fracture	With Fracture
0–20	7	1	1
20–40	10	7	3
40–60	2	21	20
60 Plus	2	17	10

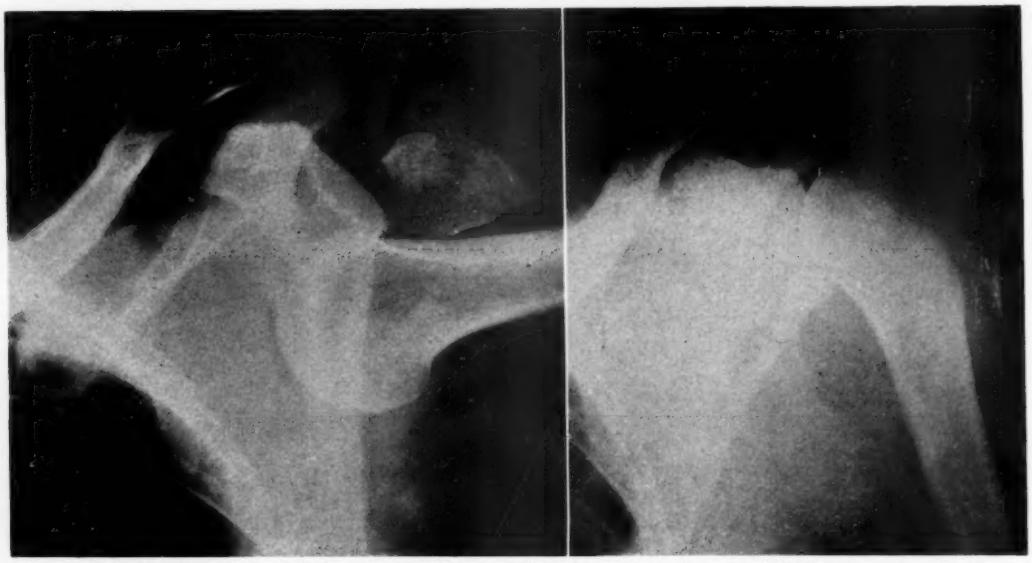


FIG. 3. Despite the original deformity early operation for repair of the residual tuberosity displacement disclosed the anterior capsule and glenohumeral ligaments to be intact.

between twenty and forty years of age and in only 10 per cent of all patients over forty there was recurrence. It is also noteworthy that 71 per cent of all recurrences were in males.

The incidence of recurrence then is extremely high in the young, especially the young male, and decreases up to the age of forty after which it is very low. Prolonged immobilization of the young recurrence-prone group as reported by Nicola, even when aided by fixation of the anterior capsular structures due to postoperative fibrosis, does not prevent recurrence. There is no sure cure for recurrence once established. It is submitted, therefore, that early operative repair of the damaged anterior joint supports warrants serious consideration in all primary traumatic anterior dislocations without fracture encountered in young male patients. This was advocated by Nicola in 1942[8] and only by such a program does it seem possible to hope for healing per primam of the disrupted joint supports and reasonably certain prevention of subsequent recurrent episodes.

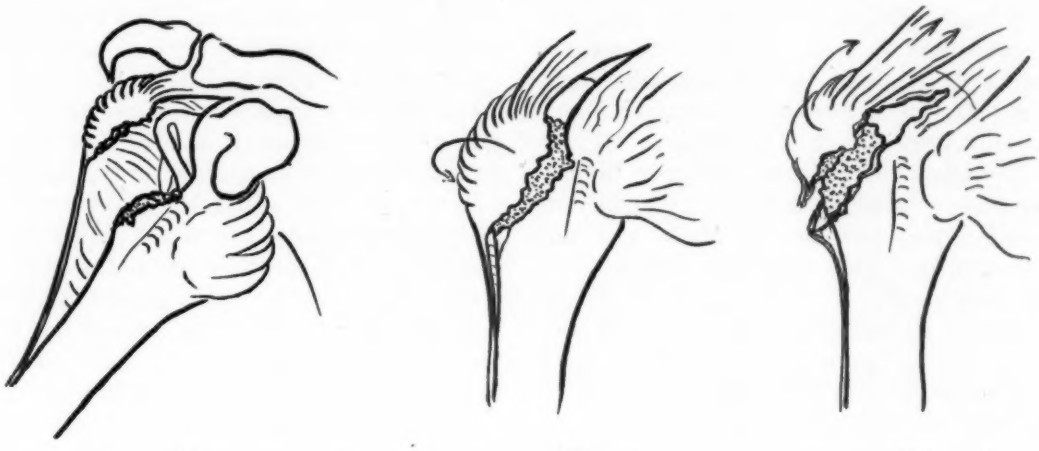
INTERNAL DERANGEMENT OF SUBACROMIAL MECHANISM

The attention of surgeons has remained focused upon recurrent dislocation almost to the exclusion of a more common and often a more disabling complication, namely, internal derangement of the subacromial mechanism. This syndrome usually consisted of painful shoulder, limited motion, inconstant subdeltoid tenderness and an undue delay in recovery following dislocation. A true "frozen" shoulder not uncommonly supervened and some permanent disability was the rule. In the cases studied, excluding those complicated by nerve injury, this syndrome accounted for the majority of results considered unsatisfactory because of prolonged recovery time or persistent symptoms and disability.

Subacromial Derangement Due to Tuberosity Displacement. Thirty-four patients had disruption of the posterior supports of the joint as evidenced by greater tuberosity avulsions. Nerve injury occurred in more than 30 per cent of these cases and in less than 5 per cent of all other cases. It is an interesting point of conjecture whether this marked difference in incidence was due to the fact that in the presence of posterior support damage the intact anterior supports of the joint maintained the humeral head in close proximity to the neurovascular bundle even when dislocated, or to some peculiarity in the cause of dislocations characterized by a posterior pathologic condition, or both. The pathomechanics of these lesions were suggested in 1944[9] and subsequent operative findings consistently have confirmed the relative intactness of the anterior capsule and glenohumeral ligaments in the presence of an avulsed greater tuberosity. (Fig. 3.)

Spontaneous anatomic replacement of the tuberosity fragment accompanied reduction of the dislocation in twenty-four cases. In these

cases the fracture was then ignored and treatment approached that given for lesions unaccompanied with fracture. (Tables II and III.) No fragment displaced as a result of early motion and all healed to the humeral head by bony union. Nevertheless, regardless of the position of the tuberosity fragment recovery was markedly delayed in almost every case. Eight cases required three to six months and fourteen cases six to twelve months before full elevation was regained. In ten cases full elevation was never regained. Some permanent defect in external rotation remained in thirteen cases.



4A 4B 4C

FIG. 4. The residual position of the tuberosity fragment depends upon the site and extent of damage to the proximal tendon cuff or distal periosteal sleeve.

Incomplete replacement of the tuberosity fragment accompanied reduction of the dislocation in ten cases. All but two of these were explored and the fragment either excised if small or comminuted or reduced and fastened in place. In either event all soft tissue damage was carefully repaired. The findings were uniform and demonstrated unequivocally that maintenance of reduction of the fracture was dependent upon the integrity of the adjacent soft tissues and that displacement of the fragment resulted from a laceration of the proximal tendon cuff or the distal periosteal sleeve, or both. Damage to the periosteal sleeve allowed an abduction tilt of the tuberosity fragment (Fig. 4C) and, when accompanied with gross cuff damage, the fragment retracted up under the acromion. A splitting of the tendon cuff unaccompanied with marked damage to the periosteum often allowed a residual external rotation tilt of the tuberosity fragment. (Fig. 4B.) Secure repair of all lacerated soft tissues proved essential to a good result. The displaced bone fragment, *per se*, appeared to be of less importance and was usually excised except when large and hard enough to be useful as a point for fixation of the tendon cuff to the humerus. Coincident division of the coraco-acromial ligament was carried out as a routine policy and the acromion was also removed in appropriate instances.

Residual tuberosity displacements of 1 cm. or more in any direction following reduction of the dislocation proved pathognomonic of extensive cuff tears and productive of major permanent disability. By far the best results in such lesions followed early operative repair. Residual displacements of 0.5 to 1 cm. usually were followed with some permanent disability often sufficient to require late operative intervention. Late operations of necessity consisted of some plastic revision of the malunion designed to restore a smooth surface for passage under the acromion and coracoacromial ligament. At times the results of this type of procedure left much to be desired and were rarely as good as can be achieved consistently with early repair. Residual displacement less than 0.5 cm., while usually characterized by delayed recovery, only occasionally produced late symptoms and disability sufficiently severe to justify operation. However, it should be stated that when the deformity consisted of an external rotation tilt (Fig. 4B) the amount of actual displacement was very difficult to determine until the

fragment was shown in true profile in the roentgenogram.

Subacromial Derangement Due to Cuff Tear. Forty-six cases were complicated by neither recurrence nor tuberosity fracture. Thirty-eight of these patients were past forty years of age. (Table v.) Fourteen of the latter group suffered from persistent symptoms and disability and had definite clinical evidence of cuff ruptures. All had some permanent functional defect and in five cases operative repair of the ruptured cuff was necessary. Of the thirty-two cases showing no evidence of cuff damage, only two patients had any permanent functional defect and one of these was not reduced until six weeks after dislocation.

It is noteworthy that 30 per cent of all non-recurring dislocations had markedly delayed recoveries, persistent symptoms and some permanent disability due to internal derangement of the subacromial mechanism. These patients were uniformly middle-aged or older. Not only was the incidence of this complication greater than that of recurrence but also, by comparison, the disability it produced was more than that suffered by the average patient subject to recurrent episodes. A paucity of comments in medical literature concerning this complication suggests that it is generally neglected or unrecognized. It has proven well worthy of notice and, when necessary, quite amenable to operative repair.

SUMMARY

The authors were unable to find authoritative or documented evidence that any form of conservative treatment prevented all dislocations of the shoulder from recurring. The trends indicated by this preliminary study suggested, on the contrary, that treatment of the primary episode was of little importance and that the site and nature of the primary pathologic disorder was of utmost importance in determining whether or not recurrences would take place.

The incidence of recurrence was 90 per cent in patients under twenty years of age, 60 per cent in patients between twenty and forty and only 10 per cent in patients over forty. This would appear incompatible with theories that recurrence depends upon specific details of treatment or mechanisms of injury. It might be postulated that one explanation of this age incidence depends upon the balance of strength between the anterior and posterior joint supports at different ages. In the young both the tendon cuff and the humeral head are strong but also supple and elastic as compared to those in older persons in whom both become progressively weaker and more brittle. This fact of attrition may predicate that during youth the glenohumeral ligaments are the weaker components of the joint supports which give way first under stress. In any event recurrence of a traumatic lesion depends essentially upon rupture or avulsion of these ligaments. Comparable damage to the ligamentous supports of most other larger joints warrants early operative repair since neither in the shoulder nor any other joint do such lesions often heal in a functionally satisfactory manner. It is submitted, therefore, that in the appropriate age groups these avulsed or ruptured glenohumeral ligaments deserve early operative repair as the only reasonably sure method of achieving healing and preventing the great majority of recurrent dislocations.

There was definite evidence that the posterior supports of the joint were the weaker component which gave way to allow dislocation in about 70 per cent of all patients past the age of forty. Was this because the attritional changes of advancing years had made both tendon cuff and tuberosity weaker and more brittle? Such dislocations in theory should not and, in fact, did not recur but were prone to nerve injuries, delay in recovery and permanent disability of some degree resulting from internal derangement of the subacromial mechanism. This syndrome proved more common and disabling than recurrent dislocation but could be anticipated consistently by roentgenographic demonstration of residual tuberosity displacement or clinical evidence of cuff damage. Early identification and operative repair proved by far the best treatment for properly selected lesions of this type with operative revision following the establishment of late symptoms a poor second choice.

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TENNIS ELBOW

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THE malady described under the names of tennis elbow, epicondylalgia externa and others is a not uncommon one. The fact that it does not have a specific name should not prevent its recognition. Inspection and palpation are the only clinical tools necessary to make the diagnosis. Despite this it is frequently missed. The economic loss to those affected by the lesion is demonstrated by one of our series of fifty cases. Twenty-one patients continued to be employed and twenty-nine were disabled. The average time lost by those disabled was seven and a half months. The condition is apparently a self-limited one. Recovery seemingly occurs in two to twenty months with or without treatment. Peculiarly enough, recurrence is practically unknown.

This contentious subject has been investigated by and theorized about by active and passive athletes, armchair and practical laboratory workers, and speculative and empirical surgeons. A study of more than 200 cases of tennis elbow in general and fifty-six in particular has left the conviction that although much has been written about the condition little is known of its actual pathology. Direct violence over the region of the external epicondyle was the mechanism of injury in a ratio of better than 2:1 in our cases. The right external epicondyle was involved four times more frequently than the left. Males were affected five times more often than females. The lesion occurred in patients between the ages of twenty to sixty and was most common in the fourth decade. We have also seen several cases in which the internal epicondyle was involved.

Theories of the etiology of the condition proposed in the literature since the early eighties embrace almost anything that one might imagine could happen in the region of the elbow joint, namely, periostitis, tendinitis, synovitis, bursitis, partial or complete tear of the common extensor tendon and partial or complete tear of the extensor carpi radialis brevis. We have never had any real proof that a partial tear of the common extensor tendon or any muscle of the extensor group was causative of the condition. Must those lesions due to minor direct violence (two-thirds of all cases in our series) be accounted for on a different pathologic basis than those due to indirect violence? Clinically, the syndromes are practically identical. It is impossible for us to believe that those cases which occur following direct violence can be explained by bursitis, synovitis or a partial tear in or about the origin of the tendon. Although the complex of the so-called "internal epicondylitis" is rare, it definitely does occur and closely mimics the clinical picture seen when the lateral surface of the joint is affected. Must then still another lesion or lesions be indicted in this syndrome?

In the cases due to direct injury the usual history is that of one or more minor blows over the epicondyle—the type of blows which nearly everyone suffers from time to time. Rarely is the violence more than a minor one. In the cases due to indirect trauma there is usually a history of persistent repetition of certain movements. Usually the offending movement is one taken up for the first time, is greatly increased in frequency or is resumed after a more or less lengthy rest period. To date only two pathologic explanations can be accepted and the second one is questionable: (1) the true Osgood's bursa which lies beneath the common extensor tendon and the head of the radius; (2) a thickened synovial fringe of the elbow joint which is seen to lie between the head of the radius and the capitulum of the humerus. This fringe or tongue may be partially torn; and when it is allegedly the causative agent, it is a definitely thickened, injected portion of the synovia which supposedly acts much as a torn or cystic semi-lunar cartilage. Again it may be asked: How can this occur following one minor trauma? Even at best these two etiologic factors explain but a small percentage of the cases.

With the hope that adequate biopsy material might throw some light on the underlying pathology, centimeter-wide strips of the com-

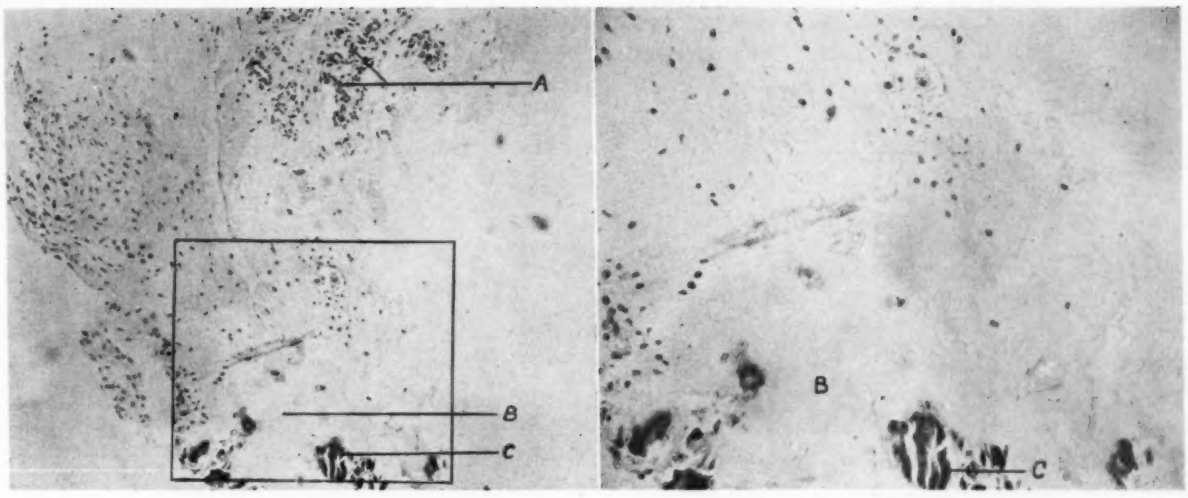

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FIG. 1. Low power photomicrograph of a biopsy specimen removed from the origin of the common extensor tendon during operation on a case of chronic external epicondylitis. A, increased cells and small vessels; B, hyalinization and degeneration of the tendon; C, calcification in the degenerated area.

FIG. 2. High power photomicrograph of the area enclosed by the lines in Figure 1A, showing (B) degenerated tendon and (C) calcification.

mon extensor tendon were taken from nine of the patients who underwent surgery. The biopsy specimens started at the epicondyle including such periosteum as was scraped off with the periosteal elevator and extended beyond the musculotendinous junction. Muscle biopsies were also taken. The individual muscle bellies were carefully explored. The patients were routinely operated upon under a tourniquet. Actual serial sections of the specimens were not made but sections were made at 3 to 4 mm. distances. The reward was meager. The microscopic sections studied by several different observers revealed a slight increase in the smaller vessels and an increase in cells. (Fig. 1.) Both of these findings were of a rather spotty nature. Four of the cases showed minute focal degeneration of tendon tissue, some with hyalinization, and in these an occasional section where the deposition of fibrin was suspected. Many of the sections showed the deposition of small amounts of calcium. (Fig. 2.) These were too small, too few and too scattered to have been detected by x-ray examination. The cells which we thought might be increased were not of the round cell type but were ovoid or even spindle-shaped, with large pale nuclei and somewhat scanty cytoplasm. They were most frequently found in those areas in which there was an increase in the blood vessels and they were often, although not always, grouped around these vessels. To determine whether or not these findings were of significance, seven similar control specimens were taken during postmortem examinations. These revealed a similar grouping of the vessels and cells although it was thought that both were definitely less numerous. None of the control specimens showed degeneration of tendon tissue or the deposition of calcium. The question then arose as to whether or not the positive findings in the biopsies could not have been due to previous treatment. We had about concluded that this was true when a section taken from a patient who had received no treatment showed the most marked changes in the series. Our conclusion was that the findings were not consistent with an inflammatory process in either the tendon, periosteum or muscle. There was no evidence of fibrosis to indicate a partial tear of either tendon or muscle.

The symptoms complained of are so varied that they cannot be called indicative of the condition. The complaint may be of pain along the outer side of the distal half or third of the arm, generalized pain about the lateral surface of the elbow, pain in the antecubital fossa and pain along the proximal third of the posterolateral surface of the forearm at times radiating to the wrist and hand. The patient experiences pain and weakness in attempting to lift an object such as a book from a flat surface with the elbow extended and the forearm pronated. However, he can do it with the elbow flexed

and the forearm supinated. The pain is worse when the patient first starts to use the extremity in the morning; it wears off somewhat with activity and returns toward the end of the day. Many patients have dull, gnawing pain at night. Numbness of the forearm, hand and fingers, which does not follow nerve segments, is a not infrequent complaint.

The signs of the condition are striking. Examination should be made with the patient seated on a stool with the arm and pronated forearm lying on a hard table, the elbow extended and the wrist projecting beyond the edge of the table. Dorsiflexion of the wrist causes pain along the proximal half of the anterolateral surface of the forearm. This is markedly increased when attempted against resistance. Extension of the fingers with the wrist palmar flexed also produces pain in the region of the common extensor tendon. The pain is most marked with attempts at extension against resistance of the middle and ring fingers. Tenderness is always present; it is usually found over a very small area on the anterolateral surface of the external epicondyle. This is best palpated for by tightly rolling a small piece of cotton onto the end of an applicator and starting well away from the expected site of tenderness with the elbow flexed. This tenderness amounts almost to point tenderness and will seldom cover an area larger than 6 by 6 mm. If these signs are present, the patient very probably falls into that group having epicondylalgia externa of unknown etiology.

In those cases in which the condition is caused either by radiohumeral bursitis (so-called Osgood's bursa) or to a thickened synovial fold in the elbow joint, the signs are somewhat different. In the so-called radiohumeral bursitis the tenderness is localized over the radiohumeral joint. The tenderness due to a thickened synovial fold is likewise over the radiohumeral joint rather than over the epicondyle. In the latter the sign which is supposed to be of greatest importance is that of spring motion in the elbow joint. This is best elicited with the dorsal surface of the arm lying on a hard table with the elbow semi-flexed. The point of tenderness over the radiohumeral joint is localized and the elbow is forcibly extended. This greatly increases the pain and the examiner has the distinct feeling of spring motion within the joint. In none of our cases have we seen any signs of inflammation. In no case was atrophy of the muscles of the arm or forearm noted. X-ray studies were negative except in two cases in which faint, wisp-like calcifications were seen close to the epicondyle.

Treatment is in great part based on the patient's occupation. Those subjects whose jobs are sedentary can usually be handled conservatively. Operative treatment should be considered more seriously for those engaged in manual work. Initial x-ray therapy should be offered to both groups since it has been the best conservative treatment in our experience. We have used four to six treatments at twice weekly intervals with an estimated tissue dose of 200 r per treatment.

A light molded leather and metal splint which limits dorsiflexion of the wrist to 10 to 15 degrees affords comfort to many patients engaged in work which requires light manual duties. Complete immobilization which extends from the upper arm to the metacarpophalangeal joints, with the elbow in flexion and the forearm in a neutral position, will relieve the pain. How long should one leave the cast in place? Three to four weeks should be a sufficiently long trial. If a cure has not been attained at the end of that time, further immobilization is contraindicated.

If one can be sure of the presence of Osgood's bursa or a deranged synovial fringe, time will be saved by operative intervention within the first four to six weeks.

Our belief at the present time is that the manual worker whose condition has not responded to x-ray therapy and immobilization after five to six weeks should undergo surgery. The common extensor tendon is stripped from its origin. If desired the elbow joint may be explored. We hold this procedure to be entirely empirical. Following it, nonetheless, recovery is usually complete in ten to fourteen weeks.

Routine physiotherapy is worthless. Certain types of osteopathic manipulations have won favor, especially with the British. Cyriax in 1936 reported twenty cases, in sixteen of which the patients were cured in a very short period of time with his maneuver. Its effectiveness in our cases has, at best, been uncertain. Several other similar maneuvers have been described which are performed with the same aim in view. Procaine injections give relief as long as the drug is acting. Aside from the acute cases it has been valueless in our hands.

CONCLUSIONS

The etiology of the affliction called tennis elbow is unknown except in the cases explained by the presence of Osgood's bursa and those possibly explained by a thickened or torn synovial fringe of the elbow joint. If in the future this fact is clearly faced, it may be hoped that more astute investigators will discover the lesion which will satisfactorily explain the cause of the symptoms in the majority of these cases.

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COLLES' FRACTURE

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WHEN numerous methods of treatment are described for any common condition, it is probably true that each of the methods is deficient in some respect or that if left alone time will cure the individual in spite of the doctors and their methods. It is also equally true that in many instances a dictum, laid down by an individual who was in his day quite forceful and highly respected, has been repeated again and again over the years until it has become folklore and has taken on the aspects of truth by repetition rather than by scientific proof. We refer, of course, to the oft repeated injunction to break up impaction by hyperextension. As a matter of fact even the mechanism of Colles' fracture has been described many times erroneously. We are just as guilty as anyone else in this matter and have in previous communications suggested that the lower fragment rode upward into and around the upper fragment. This, of course, is not true and it has remained for Lewis to describe the mechanism of the fracture as it really occurs. He says that when the outstretched hand strikes the ground, it stops. The rest of the individual keeps on going with a definite velocity in a forward and downward direction thus driving the upper fragment down into the lower. As the upper fragment is continuing in an arc around this lower fragment, a compression fracture is created on the posterior surface and a distraction fracture on the anterior surface of the lower part of the radius.

This, therefore, leads us to the conclusion that hyperextension to break up impaction is not indicated. Impaction (that is, the pressure part of the engagement of the fragments) is already on the posterior surface and hyperextension would merely increase the condition. The anterior surface is the site of a distraction type of fracture which does not have to be broken up by being pulled apart further.

Abraham Colles in his masterful article pointed out that straight traction would correct the deformity. He then suggested that rocking back and forth was to be used merely as a means of proving the diagnosis by getting crepitus or feeling the yielding of the fragments. This, of course, was before the x-ray when the fracture which was to bear Colles' name was being appreciated as a fracture for the first time because crepitus was rarely felt in these cases. However, the idea of breaking up the impaction by rocking back and forth seems to have developed in the minds of many from this suggestion of Colles, and writers on the subject have repeated it again and again for years.

Over twenty years ago Boehler pointed out that traction on the hand was a method of disimpacting the fractured fragments and many found that this could be done. However, Boehler used traction on the thumb and the fingers, the traction being applied by an individual, and it soon became apparent to anyone doing this work that the success of his case depended upon the intelligence and fortitude of his assistant. Many times the assistant tired out; many times his fingers slipped and frequently he applied more pull on the fingers than he did on the thumb of the patient.

John Caldwell in 1931 described the use of the finger-trap traction which was a mechanical means of getting the same result. This was really a distinct improvement; however, inasmuch as Boehler with his manpower type of traction had had to put the arm in a horizontal position, for a long time the finger traps were also used horizontally and to all five fingers. With this mechanical type of traction and with the hand held horizontally, the limb tended to sag into a supinated position. It also became evident that when traction was applied to any of the fingers it reduced that amount of pull on the thumb. We always like to think of the radius as an upward extension of the hand and the ulna a downward extension of the humerus, the two going together to form a forearm. If this is true, at the lower end where the fracture under discussion occurs the radius is all important and the ulna can be considered just one of Fraser Gurd's spare parts. Therefore, any traction which tends to deviate the wrist and

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FIG. 1. Shows how traction on the thumb throws the hand into ulnar deviation; the elbow has been fixed by a band attached to some solid place in the lower part of the table or the floor and the traction is made through some overhead connection. Orthopedic tables are well equipped for this but a pulley and home-made attachments will serve. One should have several sizes of finger traps.

FIG. 2. Shows the palmar flexion which develops when, while still maintaining thumb traction, the hand is rotated into pronation.

FIG. 3. Shows how the pads are placed to protect the points where there will be pressure.

hand toward the ulna will develop more force on the radius than if said traction is applied in a straight line. In considering the embryologic development from the one-toed to the five-toed animal the single toe is represented by the middle finger. This may be true but, nevertheless, with the forearm and wrist structure of man as it is it becomes quite evident that pull on the thumb alone directs a greater force on the radius itself and also tends to deviate the hand in the ulnar direction which is valuable in the treatment of this type of fracture, for the unfractured or only slightly fractured ulna may be used as a prop against which pressure may be made and length of the radius maintained. (Fig. 1.)

It is further suggested that in the nature of the fracture and the mechanics of the injury the hand must have gone toward supination quite forcibly at the time the bone broke. Therefore, pronation should be a corrective maneuver. In other words we have here an injury in which there is a violent compression between the hand and the forearm, most of which is taken up by the posterior part of the radius and very little by the ulna, together with a supinating deformity. The result is the common Colles fracture which is a backward rotation of the lower fragment with severe compression on the posterior side and a backward angle of the lower articular surface of the radius. In the treatment, therefore, if good traction on the thumb can be applied and if good ulnar deviation can be maintained and pronation with some palmar flexion gained, we should be able to splint the wrist in a good position and at the same time give the patient the chance to use all of his fingers without difficulty. (Fig. 2.) This combination should give us a good result in the long run. We use the phrase "long run" advisedly for in many articles it is pointed out that once the reduction has been attained further deformity will not recur easily and, therefore, long splinting is not necessary. We disagree entirely with these statements. We will show that when the reduction has been attained there is an open space on the posterior surface between the fragments, a V type shape of space which will not fill with bone for a long time. Therefore, it is necessary to keep the splinting up for many weeks or the deformity will recur. Further than this, if the hand is so splinted that the fingers can be used, one does not have to fear frozen fingers and, therefore, there is no need to take the splint off early. In splinting these cases we use, of course, the skin plaster cast; however, a heavy pad is placed over the radial side of the metacarpal of the index finger and another pad over the ulnar side of the lower end of the ulna. These two points can then be used for pressure

FIG. 4. A, lateral view of an ordinary Colles fracture before treatment; B, the same case a few minutes later with thumb traction and pronation; note the open space between the posterior edges of the fragments.

points and, by using the ulna as a prop and maintaining ulnar deviation by pressure on the second metacarpal, radial length can be maintained. (Figs 3 and 4.)

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DISCUSSION OF PAPERS BY DRS. CAVALLARO AND McLAUGHLIN, MEHERIN AND COOPER, AND CAROTHERS AND BERNING

PRESTON A. WADE (New York, N.Y.): I am very interested in this discussion of traction in treating Colles' fracture because we in New York have recently had two illustrations very similar to that about which Dr. Carothers has told us.

We were entertained in Boston by the Fracture Committee and were given a very wonderful demonstration by Dr. Cave at the Massachusetts General Hospital. He gave us a demonstration very similar to this although he used traction on the thumb only by means of what appeared to be a half-hitch. He did not use the Japanese trap. I think both of them may be very dangerous. I have seen cases in which the thumb has been damaged by too long and steady traction. However, Dr. Cave presented a series of cases which was very well done. Also, he gave us a new idea, or new to me at any rate, in that he used only a lateral gutter for immobilization, stressing the point that the thumb should be caught in this gutter and that the ulnar side of the forearm is not splinted at all. I have not used this method as yet nor have I used the trap method but I am very much interested.

Another one of our demonstrations was given by Dr. Cassebaum at the Roosevelt Hospital, where they use five-finger traps with the Japanese handcuff, using a method similar to that which has been described here. As I say, we have not used it; but as Dr. Lindem and I have just remarked, we have heard it three times so there must be something in it.

OSCAR P. HAMPTON, JR. (St. Louis, Mo.): I was somewhat bowled over by Dr. McLaughlin's statement that 90 per cent of dislocated shoulders in patients under twenty years of age and 50 per cent of those in patients between twenty and forty years recur. It prompts me to try to dig out our own figures. I do not believe that fibroblasts are that rare in Missouri. Apparently the water shortage in New York has retarded the activity of fibroblasts.

Another point I wanted to raise is that all of the twenty recurrences occurred in those patients in whom immobilization or restriction of motion, as Dr. McLaughlin called it, had been maintained for less than a week. Perhaps those fibroblasts were retarded in their activity because immobilization was maintained for such a short period.

W. LARRABEE (Hartford, Conn.): I would like to discuss two points about tennis elbow. The first is that as a conservative treatment the injection of novocain and, after proper infiltration, very vigorous manipulation of the area seem to have a definite beneficial effect in a certain number of cases but by no means all cases.

The other point is the cutting of the common tendon as contrasted with periosteal stripping. I have done both, and in two of the periosteal strippings a good deal of calcification occurred which was just as bad as the original injury. In one case I had to go in and remove the calcification because it was so extensive. In the other case it cleared up gradually with conservative treatment.

KELLOGG SPEED (Chicago, Ill.): I would like to discuss two things: First, I would like to say a word about Dr. Carothers' stand regarding Colles' fracture. I would like to congratulate him for sticking to his point and, also, for spending so much time on what many of us perhaps have come to think was a perfectly finished matter of pathology and treatment in the care of fractures. His ideas are very sane and sound and, with the adaptation of traction, you will find that you can reduce quite rapidly and painlessly the most difficult fracture in that region.

The second point concerns dislocations at the shoulder. I, also am astounded at the percentage of recurrences which I have never experienced in a similar degree. It seems to me we forget in the diarthrodial joint that the shoulder is not a ball-and-socket joint such as the hip. The surface of the glenoid is not really much larger than a twenty-five cent piece whereas the head of the humerus is considerably larger and is bound on by the ligaments that have been described. However, the joint, its integrity, its range of motion and its usefulness are not matters entirely of ligamentous control; largely muscles govern and control the movement and stability of the shoulder. Consequently, you cannot rely entirely upon suturing or reattachment of the ligamentous structures to restore full function after recurrent dislocation. You have to retrain and keep strong the muscles which govern that joint in order to avoid unhappy recurrences.

I think we should make a deeper study of the anatomy and physiology there from the standpoint of the facts that Abbott has brought out recently in his very wonderful "Dissections of the Shoulder Joint."

HARRISON L. MCLAUGHLIN (closing): The high incidence of recurrence of dislocated shoulders, in young persons has been greeted with surprise. It was as great a surprise to us. The fact of the matter was that we did not know the true end results of primary dislocations nor did we appreciate that about 50 per cent of spontaneous recurrences do not begin until between one and a half and three years after the primary lesion. The problem of recurrent dislocation always has been studied in reverse. It is suggested that until an increased comprehension of the varied pathology of primary lesions is obtained no solution of the enigma of recurrence will be possible.

One wonders whether adequate fibrous healing of avulsed glenohumeral ligaments to bare bone of the glenoid rim ever occurs. The site where healing is required is constantly moving, regardless of the type or duration of external dressings, and is perfused with a continual bath of anticoagulant synovial fluid. Under such circumstances the formation of a primary clot is impeded and the task of the fibroblasts in bridging the gap must be very difficult.

RALPH G. CAROTHERS (closing): Regarding Colles' fracture I would like to say that traction does not have to be very forceful. There is no need at all to pull the thumb off and it does not take that much force. If you have a fracture of the forearm with a complete separation and the lower fragment is riding on the posterior surface of the radius, that is something else; that is not Colles' fracture. Although such cases have been handled with this method, I do not necessarily advise it.

This method is also a means of handling these cases without much manpower. You see, in some of our hospitals we do not have very many interns and we have to get along by ourselves. I can handle one of these cases with no help whatsoever except from the x-ray technician.

SKI INJURIES

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NO one can actually state the exact number of individuals who ski every winter but it is estimated by skiing authorities that in the Winter of 1948 approximately eight million people skied. When one figures that on the three major ski tows in the Berkshires of western Massachusetts and southern Vermont there are approximately six thousand people skiing every week-end, one can see the magnitude of the sport. Inasmuch as many of these skiers are inexperienced and inasmuch as weather conditions are not always ideal, injuries are bound to result. However, the percentage of injuries to the number of people skiing still remains extremely small. An estimated ratio at one of the ski resorts in the Berkshires is approximately two injuries of severity sufficient to require medical aid per every one thousand individuals. During the past three seasons we have had occasion to see and care for a number of these injured individuals, and it is on the basis of this that the present paper is presented.

There were 226 patients, of which 152 were males and seventy-four were females, a slightly higher ratio than might be found elsewhere because of the fact that a men's college is located in the geographic center of the three main ski resorts. The age incidence varied from seven to fifty-five years. The 226 patients sustained a total of 254 injuries. These can further be broken down into 124 fractures and dislocations, 116 sprains and miscellaneous injuries of various sorts totaling fourteen.

The lower extremity is obviously by far the most frequently injured, their being ninety-seven fractures and dislocations in the lower extremity. There were twenty-one fractures and dislocations in the upper extremity and six involving the trunk.

There was a total of twenty-seven upper extremity and trunk fractures and dislocations. There were four fractures of the metacarpals. This is a rather low number inasmuch as it has previously been reported that a very common injury in skiing, particularly in Switzerland, is the so-called "ski-pole fracture" which is an oblique fracture of the third and usually the fourth metacarpals. In only two instances did we see injuries simulating this, the other two fractures of the metacarpal being that of the first. There were only three fractures of the carpal scaphoid. There were three fractures of the radius, one involving the radial head with no significant displacement which was treated by aspiration and early motion, one an epiphyseal separation of the lower end of the radius in a young boy of twelve and one a fracture of the radial styloid associated with a carpal scaphoid fracture. There were three fractures of the humerus, two involving the surgical neck and the third the shaft. In one of these there was an associated subcoracoid dislocation of the fractured surgical neck and shaft. Fortunately, reduction was accomplished by closed methods. There was one complete fracture of the olecranon requiring open reduction and one fracture of the ulnar shaft associated with multiple injuries. There were four dislocations of the shoulder. It is interesting to note that one of these dislocations followed a Bankhart procedure for recurrent dislocation of the same shoulder. There were two posterior dislocations of the elbow, neither of which presented any late complications. There were two cases of fractured ribs occasioned by direct trauma and there were two cases of fractured clavicle, all associated with other multiple injuries. There was one case of fractured coccyx.

Fractures of the lateral malleolus by all odds outnumber all other injuries, there being fifty-two of a total of ninety-seven fractures and dislocations of the lower extremity; or, on a percentage basis of the total, approximately 21 per cent of all injuries seen in this area consisted of fractures of the lateral malleolus. Spiral fractures of the tibia and fibula were also surprisingly high, there being eighteen in a series of 254 injuries. There were six fractures of the femur. Of these, three were in the subtrochanteric region, one was intertrochanteric, one involved the greater trochanter alone and one was

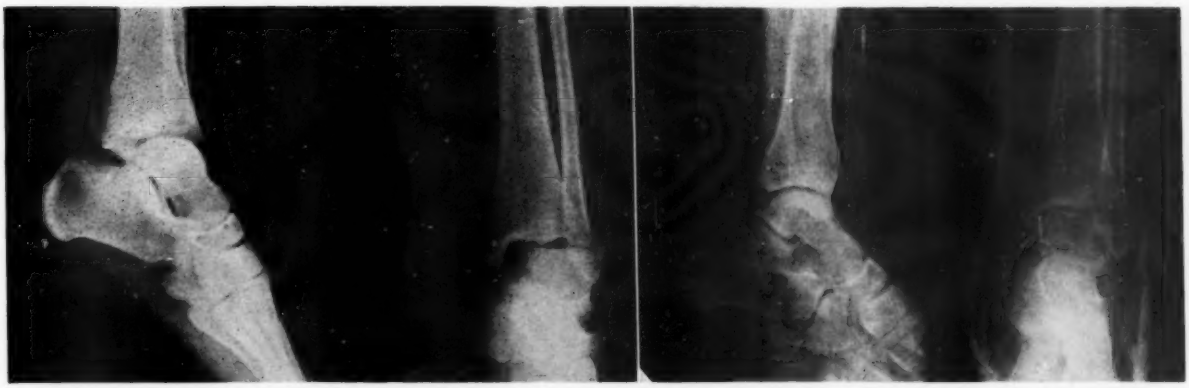

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FIG. 1. Case 1. Illustrates complete compounding of the medial malleolus with dislocation of the ankle and fracture of the lateral malleolus.
FIG. 2. Case 1. Immediate postoperative position with restitution to normal of the ankle joint.

a severe, diacondylar fracture of the lower extremity of the femur. There were ten isolated fractures of the tibia. Of these, three involved an avulsion fracture of the anterior lip, three involved the shaft, one was a fracture of the posterior lip, one was an avulsion fracture of the lateral tibial condyle, one was an epiphyseal separation with displacement of the lower tibial epiphysis in a child and one was a vertical fracture through the condyles associated with complete dislocation of the knee joint. There were only two bimalleolar fractures in this entire series. There was one fracture of the medial malleolus alone, one avulsion fracture of the anterior portion of the talus, one fracture of the metatarsals occasioned when the man fell off the top of a ski tower, one avulsion fracture of the fibular head and one avulsion fracture of the tarsal scaphoid. There were two posterior dislocations of the hip in this series and one compound dislocation of the ankle associated with a fracture of the fibula in the lower third of the shaft. One patient had complete compounding of the medial malleolus with no fracture of the tibia. (Fig. 1.) This patient was treated with immediate débridement and reduction with primary closure. The patient had made a completely uneventful recovery and has skied for two successive seasons since the injury. (Fig. 2.)

One patient presented a complete lateral dislocation of the knee joint with rupture of the internal collateral ligament, complete central avulsion of the tibial spines with complete tear of both cruciate ligaments and complete tear of both menisci with a vertical fracture of the tibia. (Fig. 3.) Immediately after injury it was reported that he had a good dorsalis pedis, but

FIG. 3. Case II. Illustrates complete lateral dislocation of the knee joint with a vertical fracture of the tibia.

when seen at the hospital after the half hour required for transportation no dorsalis pedis was palpable. Immediate reduction of the dislocation was carried out with prompt return of the pulsation. (Figs. 4 and 5.) After forty-eight hours open reduction was done with repair of the internal lateral ligament, replacement of the central fracture, excision of the menisci, removal of the frayed tabs of cruciate ligaments and bolting of the vertical fracture. (Figs. 6 and 7.) It is too early to know the end result of this case.

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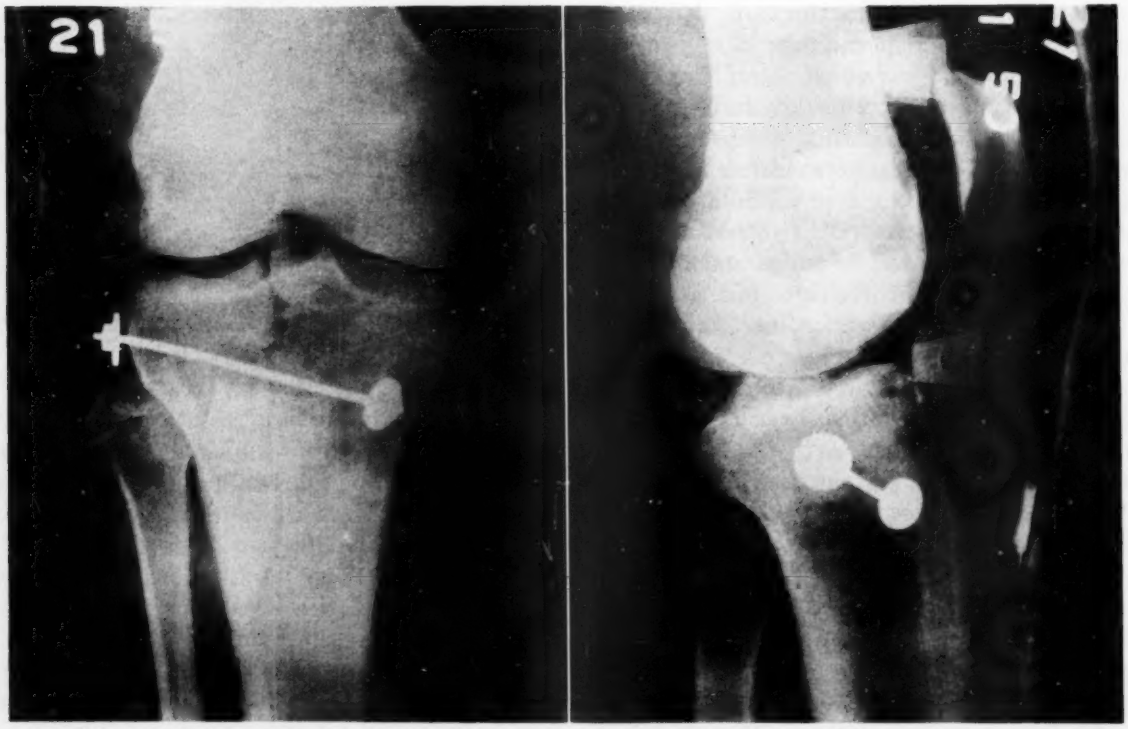
FIGS. 4 and 5. Case 11. Illustrate immediate closed reduction with large, central fracture of the tibia displaced anteriorly in the joint.



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FIGS. 6 and 7. Case 11. Show position postoperatively after repair of the ligaments, replacement of the central fracture and bolting of the tibia.

One hundred sixteen sprains were encountered. As has been previously noted by other authors, a tear of the internal lateral ligament of the knee joint is a very common sprain encountered in skiing. There were forty-seven sprains of the internal lateral ligament; in three of the cases we have had occasion to follow up the patients long enough to prove the presence of a torn medial meniscus at subsequent operation. There were forty-nine simple sprains of the ankle, all involving the external ligament of the ankle joint. The combination of tear of the internal ligament of the knee and sprain of the ankle was of frequent occurrence. There were seven acute low back strains, six sprains of the shoulder, two minor acromioclavicular sprains and five miscellaneous sprains, there being one each of the foot, elbow, hip, wrist and hand. Of the miscellaneous injuries encountered, they were all of a relatively minor nature and no complications were seen.

COMMENTS

It can readily be seen from the preceding figures that there are several injuries which seem to be predominantly present in skiing. The most frequent injury, as previously mentioned, is fracture of the lateral malleolus. In the present technic of parallel skiing with a fixed binding, incorporating the ski, binding and shoe as one integral unit, it is quite obvious that a twisting injury will result in stress thrown on the area immediately at the top of the boot which is usually the area of the lateral malleolus. Fractures of the lateral malleolus have all followed an almost identical pattern and x-rays can practically be superimposed one upon the other. In only three of the fifty-two cases was any widening of the joint mortice demonstrable either clinically or by x-ray and in only one was there a mild degree of posterior dislocation of the astragalus. Uncomplicated fracture of the lateral malleolus was the most common injury sustained by beginners. It is interesting to note that of a total of fifty-two fractures of the lateral malleolus eight were received while going uphill usually on a ski tow. The individual putting on skis for the first time immediately tries the ski tow. With a sudden lurch she (or he) is pulled up the slope, the skis cross and the total statistics of fractures of the lateral malleolus is increased by one. Statistically then, 15 per cent of all the fractures of the lateral malleolus incurred in this series were received by patients falling down while going uphill. We believe that the combination of a fixed binding plus a person who is inexperienced in skiing, and more important, inexperienced in falling, causes a torsional mechanism directly at the top of the ski boot with the resultant oblique fracture of the fibula just above the level of the ski boot itself.

If we compare these figures with the spiral oblique fractures of the tibia and fibula, we see an entirely different story. Here the mechanism is one of a severe torsional strain usually occasioned when the patient was going downhill at a rather high rate of speed and struck either a bare spot or a hole in the snow. The majority of these spiral oblique fractures of the tibia and fibula, as well as the femoral fractures, occurred in experienced skiers. In reviewing the mechanism of femoral shaft fractures in four of the six we have definite information that the patient struck a tree in falling. Sprains of the internal lateral ligament of the knee joint were also usually associated with a torsional strain with the ski fixed and the body rotated as the knee was adducted at the same time. Ankle sprains were probably occasioned by the same mechanism as fibula fractures but not of as great severity. Twenty-one of the patients showed multiple injuries, the majority being a combination of knee and ankle injuries.

Approximately 90 per cent of all injuries occurred after 3 P.M. It seems most likely that two factors existed to explain this: First, as previously mentioned the majority of the injuries occurred in the inexperienced who were out of training and who toward the end of the day were tired, with slower reactions. Second, at about 3 P.M. the sun would usually go down and ski conditions would change during the brief time required to go up the ski tow and take another run down the trail, with the snow being much faster than it had been a half hour previously. All of these factors probably played a part in the incidence of fractures and sprains in the inexperienced skier.

TREATMENT

The first-aid treatment of these individuals was usually given by the National Ski Patrol at the ski resorts, and here parenthetically I would like to praise the method of handling these injured individuals. In spite of the fact that many of them had to be transported by toboggan down a long, difficult trail they would always

arrive in excellent condition and had received splendid first-aid emergency splinting. The Thomas splint was used routinely on femoral shafts but a modified gutter splint was used on ankles and lower leg fractures. This seemed to give extremely adequate immobilization for transportation a distance of 15 miles to the nearest hospital.

The treatment of the injured individuals varied with the type of injury and with their decision whether to undergo definitive treatment in the local hospitals or to be returned to their home towns. In the event that the patients elected to return to their homes for further therapy, in fractures of the fibula they were routinely immobilized in a short leg plaster which was partially split, the patients being kept overnight for observation and then allowed home and referred to their local doctors together with x-rays. Fractures of the shaft of the tibia and fibula were transported in a long leg plaster cast and fractures of the shaft of the femur in a traction splint, either with or without plaster of paris incorporated in the splint. In those individuals in whom definitive treatment was carried on locally open reduction was resorted to in the majority of the cases of spiral oblique fractures of the tibia and fibula. (In a total of ten open reductions performed there was one case of delayed union which required a subsequent bone graft.) Fractures of the femur were treated variously with skeletal traction and with internal fixation. Fractures of the lateral malleolus were evaluated very carefully to make sure there was no diastasis of the joint mortice and no severe tear of the intrinsic ligaments of the ankle joint. If we were convinced that there was no major tear and that there was no widening of the mortice, ethyl chloride spray followed with early ambulation was permitted within the limits of pain. We have now followed up a rather large group of these consisting of about twenty-five over a period of three years; in all of the patients weight-bearing was complete within the first ten days following injury and disability was practically zero within two weeks. Intensive physiotherapy in the form of whirlpools and massage was instituted on the day following injury and daily thereafter until the soft tissues had returned to an appearance of normal. If there was any suggestion of pain on weight-bearing after the ethyl chloride spray, no weight-bearing was permitted until the situation was further evaluated after twenty-four hours. In no case which we have followed up for more than two years have we found any tendency toward recurrence of ankle instability or of any other disability. It is interesting to note that in one individual a fractured lateral malleolus of the left ankle was sustained one year and the following year while skiing an identical fracture of the opposite side was sustained. If there was any suggestion of widening of the mortice or of any major tear of the intrinsic ligaments of the ankle joint, plaster of paris immobilization was carried out with weight-bearing being allowed at the end of one week by means of a walking heel incorporated in the cast. Immobilization was continued for a minimum of three and a maximum of six weeks following this therapy.

We wish to stress the point that early ambulation is not advocated as a general rule for fractures of the lateral malleolus and should never be used in the hands of the inexperienced. It is only in the occasional case in which the injury can be very carefully evaluated and followed up with the utmost care that this method of treatment is at all applicable.

Sprains of the internal lateral ligament of the knee joint were treated with a good deal of conservatism both because of the danger of laxity of the ligamentous structure and because of the possibility of an internal meniscus injury. Compression dressings were applied immediately and ice packs applied, with elevation of the part. If there was any suggestion of instability, the leg was immobilized in a plaster cylinder. If there was no instability, physiotherapy was instituted early and gradually increasing weight-bearing allowed depending upon the amount of hemarthrosis present. In only two instances was aspiration of the knee joint necessary, with early application of a pressure dressing. All individuals were warned as to the possibility of a future internal derangement of the knee joint. Minor sprains of the ankle without any demonstrable instability were treated with ethyl chloride spray, with immediate ambulation. In all of these recovery was rapid and complete within a week.

SUMMARY AND CONCLUSIONS

A survey of 226 patients representing 254 injuries incurred while skiing is presented. Figures are shown giving the incidence of injuries to the lower extremity, particularly to fractures of the

lateral malleolus and to sprains of the internal lateral ligament of the knee joint. Recommendations as to the type of treatment to be carried out are given and several of the follow-ups shown by means of x-rays.

From this study it would seem that two recommendations might be made to reduce the incidence of injuries to the lower extremities which comprise 203 of a total of 254. In the first place adequate instruction and training in skiing should be obligatory before the novice is allowed to use the ski tow. In the second place, as previously mentioned, the fixed binding undoubtedly plays a large role in injuries to the lower extremities. Reports have been made now of the use of the so-called "safety binding," with definite reduction in the accident rate. It would seem that the more universal use of the "safety binding" would certainly minimize the incidence of fractures of the lower extremities, particularly of the ankle, as well as sprains of the internal lateral ligament. It is interesting to note that of this total of 226 patients with 254 injuries not one person was wearing "safety bindings" at the time. In the case reported in detail of dislocation of the knee the patient routinely used the "safety binding" but that day had changed to conventional skis. We believe that with more general acceptance of this type of binding injuries could be reduced markedly.

DISCUSSION

STEPHEN S. HUDACK (New York, N. Y.): It is comforting to see that the injuries described by Dr. Coughlin are common to many other forms of violence including dancing. The predominance of fractures of the lateral malleolus in beginners is understandable except that whereas lateral malleolar fractures usually occur when the foot is fixed and the body moves in the ski tow, apparently, the body is fixed and the foot is twisted. The mechanism of fracture in experienced skiers sustaining femoral and tibial fractures on striking a tree suggests errors in timing of these athletes, when the skier makes up his mind just an instant too late. What would happen if the skier could not make up his mind and sustained diastasis of the pelvis and straddled the tree? The answer is obvious. If he fell into the hands of the authors, he would do well. The author's reference to fractures of the anterior lip was a little unclear. I assume Dr. Coughlin means the anterior lip of the tibia at the ankle joint. Anterolateral avulsions in those cases can sometimes be troublesome later on because they rip the capsule and there is a redundancy of the capsule and the synovia, with inflammatory tissue which can be painful in dorsiflexion when squeezed between the talus and tibia. Sooner or later the patient has to go somewhere to be relieved of the pain.

A. M. OKELBERRY (Salt Lake City, Utah): I have just a word or two about our experiences here in Salt Lake City. We do have a considerable number of skiing injuries and we have been struck by the exceptionally fine care, first aid and transportation that our patients with ski injuries receive.

The ski patrol is sponsored by Salt Lake City and County combined and paid for and equipped by these city and county organizations. The ski patrol people themselves are experienced skiers and are on the job in a very short time, in just a matter of minutes, to render first aid to the injured.

To my knowledge further injuries have not occurred during the period of handling and transportation, and I think our skiers themselves, too, are learning more and more all the time about ski injuries and therefore take better care of them. We had one patient some time ago who received a spiral fracture of the femur and remained standing until the ski patrol took hold of him, splinted the leg and laid him down. Our people are apparently pretty well aware of the dangers that might occur by mishandling.

I have also been struck by the rapid recovery that many of our patients make from spiral fractures of the tibia in which complete reduction and fixation with screws were done. We had one ski instructor last winter who was, against our advice, walking and carrying on essentially normal activities at the end of nine weeks without trouble following her spiral fracture at the junction of the middle and lower thirds of the tibia. She was a ski and swimming instructor at the University of Utah and was an athletic individual who apparently healed a little faster than most of our patients.

One thing I would like to emphasize is the recognition of medial ligament injuries at the ankle associated with fractures of the fibula low down or just of the external malleolus. To our surprise not long ago we noted the presence of a small fragment at the tip of the medial malleolus and decided it should be taken out; when we explored this area, we found there was a complete avulsion of the entire ligamentous support of the medial side. A patient can come in with his dislocation reduced as part of the first aid care, yet have a very severe ligamentous injury in which repair is indicated.

Our results in injuries of the ankle have likewise been very much better since we have been doing open reduction and fixation of medial and lateral malleolar fractures. The use of wire or an occasional screw through the oblique fractures in the lower portion of the fibula has given excellent results.

I think these patients get back to active motion faster, with less pain, and make a more rapid recovery.

I should like to add my thanks to the essayists for the presentation of experiences in the Berkshires.

EDWARD J. COUGHLIN, JR. (closing): In answer to Dr. Hudack's question about our remark of the ratio of 2:1, I do not think those figures would be found generally. However, we happen to be located in the geographic center of a men's college and a good percentage of the patients were college students.

As to the diastasis of the pelvis, one of the posterior dislocations of the hip was in a boy who could not decide which side of the tree he would go around. Fortunately, he did not have any bladder difficulty.

With regard to Dr. Okelberry's discussion, I have seen only one of the deltoid ligament tears. That was in one patient who appeared with a relatively minor fracture of the fibula almost similar to the ones we had seen previously but who had very marked tenderness over the deltoid ligament. We did not do an open reduction but used long immobilization in plaster, and a good result was obtained. I think the situation has to be evaluated extremely carefully before the decision toward ambulation is made because if one attempts to apply early ambulation in these patients with major ligamentous tears one is going to come to grief.

We have had no experience as yet with open reduction of the fibula simply because in the cases we have been able to follow up the early ambulatory treatment of those undisplaced fractures has been satisfactory, and in a number of instances we have had occasion to take care of the patient's other ankle when it was broken the following year.

I would like to thank both of the discussers.

USE OF HOMOGRAFTS IN EXTENSIVELY BURNED PATIENTS*

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Louisville, Kentucky

A HOMOGRAFT is a transplant of tissue from one individual to another of the same species. Transplantation of tissue and of whole organs within a species or from one species to another has, in the past and occasionally at the present time, been more productive of fables than of scientific facts. At the present time the value of corneal homotransplantation is unquestioned, that of bone and cartilage is still under debate, while the practical value of the skin homograft has been only partially recognized and hesitantly used.

Numerous careful studies, both clinical and experimental, have established the following data concerning the homotransplantation of skin, with which we will be solely concerned throughout the remainder of this article:[1-13]

1. Skin homografts transplanted orthotopically, that is, to naturally skin-bearing surfaces, will take approximately as well as autografts transplanted under equivalent physiologic conditions.

2. The take of skin homografts is probably not influenced by disparity in race, sex or blood group.

3. There are probably no skin groups, analogous to blood groups, matching of which will influence favorably or adversely the take of skin homografts.

4. After taking, skin homografts not only survive for varying periods of from three to ten weeks, but actually, for a time at least, proliferate epithelium and grow briefly.

5. Ultimately all skin homografts melt away and disappear completely, the sole exception being in the case of identical twins in which the skin homografts may persist indefinitely.

6. Reports of permanent survival of homografts are errors in observation and experimental method and reflect the failure to take into consideration the survival, persistence and Phoenix-like regeneration of autogenous epithelium from deep-lying crypts, hair follicles and sebaceous glands which have been buried beneath exuberant granulation tissue or burn debris.

7. Despite the early reports of Underwood and others of severe reactions attending the breakdown of homotransplanted skin, homografts melt away in from three to ten weeks, unaccompanied with any appreciable local or systemic reaction. This breakdown and disappearance of homografts is not due to infection, vascular congestion, edema or anaphylaxis.

8. Skin homografting provokes an immune state which is systemic in compass and not confined to the neighborhood of the foreign graft. The presence of a lymphatic drainage system is necessary for the immunity to be called into being, and penetration of the homograft by blood vessels must occur before the immune state can become effective in causing the breakdown of the graft. Both of these processes are inherent in the mechanism of taking of a skin graft.

9. The skin homograft elicits, therefore, and then in the ensuing weeks submits to an immune reaction, which it has called into being and which ultimately causes its breakdown and disappearance. Subsequent skin grafting from the same donor to such a sensitized recipient elicits an accelerated immune reaction which causes rapid disappearance of the homograft in a very few days' time. Repeated homografts from the same donor are therefore useless, but homografts from fresh donors will take almost as well as at the initial homografting. Consequently it is impossible to desensitize or denature either donor, graft or recipient by any known method so as to ensure or augment survival of the graft.

10. Skin homografts as well as autografts may be stored under sterile conditions of refrigeration for a period up to three weeks, with apparently no diminution in the incidence of takes. The survival time of such stored grafts is apparently not affected by the length of storage.

* From the Department of Surgery, University of Louisville Medical School, Louisville, Ky.

It is now well established that the intelligent use of homografts as a physiologic skin dressing can be life-saving or of inestimable benefit in expediting healing and recovery in severely burned patients.[5,6,12,14,15] At the present time homografts are used to provide temporary

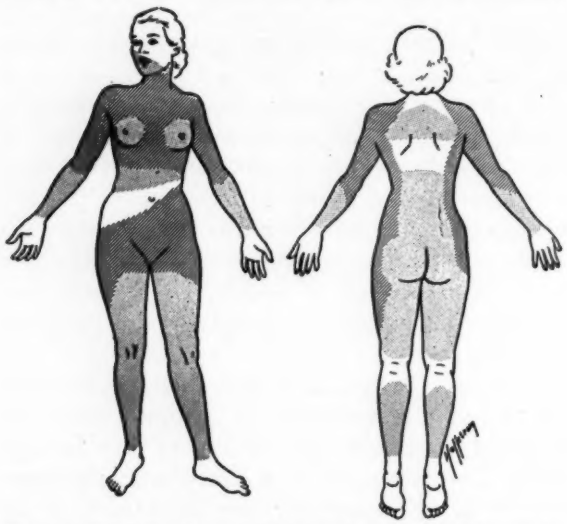


FIG. 1. Distribution of deep and superficial burns in Case 1, W. R., 17 years old. Dotted areas = 1st and 2nd degree burns. Shaded areas = 3rd degree burn with loss full thickness skin.

skin coverage (A) when autogenous skin is not available because of the extent of the burn, (B) when, although autogenous skin is available, the patient is too ill to stand a formal grafting procedure and (C) To stimulate the patient's healing and reparative processes in cases in which autogenous grafting has consistently failed.

The results of homografting are usually prompt and dramatic. Infection is brought rapidly under control; heat, fluid and protein loss is curtailed; and comfort and ease of nursing care is promoted or increased.

The following case reports are illustrative:

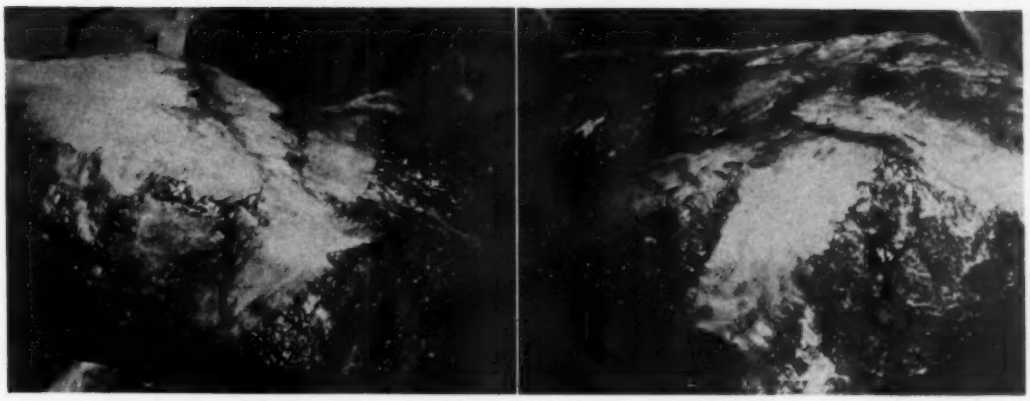
CASE REPORTS

CASE 1. W. R., a seventeen year old white female, was admitted to the hospital on November 3, 1949, with flame burns which involved 87 per cent of her body surface. The only body areas not burned were her feet, ankles, posterior neck region and hands. She was in shock on admission, and her blood pressure was estimated at about 60 mm. of mercury, systolic, and 40 mm. of mercury, diastolic. First aid burn dressings had been applied before transportation to the hospital, and she had been given morphine. Because of the depth of her burn shock, treatment was first directed entirely toward fluid replacement. The method of Cope and Moore[16] based on anticipated fluid loss was used to establish the fluid replacement schedule. A retention catheter was inserted for the determination of hourly urinary output. Whole blood and plasma transfusions replaced colloid loss into and from the burned areas. Electrolyte replacement was provided by infusions of physiologic saline and Lactate-Ringers's solution. The parenteral administration of fluid was supplemented by the oral intake of water and fruit juices. After fourteen hours the patient's condition was quite satisfactory, and fluid balance was established. She was removed to the operating room for the application of a more substantial dressing. Intravenous procaine (1,000 cc. of 0.1 per cent solution) was used for analgesia with satisfaction. The burned areas were gently washed with pHisoderm, irrigated with physiologic saline, lightly dried and covered with furacin gauze and machinist's waste pressure dressings.

Nine days later the dressing were changed under general anesthesia. At this dressing the magnitude of the burned area was fully realized. Of the 87 per cent of total body surface involved in the burn, at least half was so deep that full thickness skin loss was to be expected. There was no unburned skin available for grafting. Given time, several areas of superficial burn might heal to become available for donor sites. Homografting was resorted to to provide a temporary skin covering. (Fig. 1.)

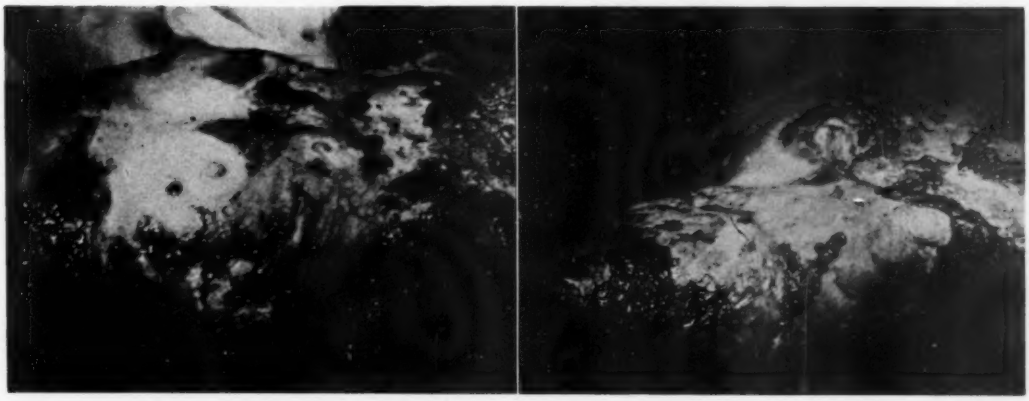
On November 26th, twenty-three days postburn, the first homografting procedure was carried out. From fourteen donors fifteen sheets of skin averaging 8½ by 3½ inches were cut freehand with the Brown-Blair knife. These donors were all males and were not selected on the basis of blood grouping or family relationship. After the grafts had been cut, the patient was brought to the operating room and grafts were applied to the denuded areas on the trunk, neck and shoulder regions and were snubbed in place, without suturing, by carefully applied furacin gauze dressings. (Fig. 2.)

The general condition of the patient improved during the next week. She seemed more comfortable, her appetite improved and nitrogen balance was not as difficult to maintain; however, the febrile course was not appreciably affected. The initial homografts remained viable after two weeks and seemed to grow by epithelialization from their edges. A little more than two weeks later a second homografting procedure was done in order to cover the remaining denuded areas. At this time a full drum of skin was taken from each of four donors with the Padgett dermatome, and the grafts were applied to the patient as before. Subsequent dressings were done at five- to seven-



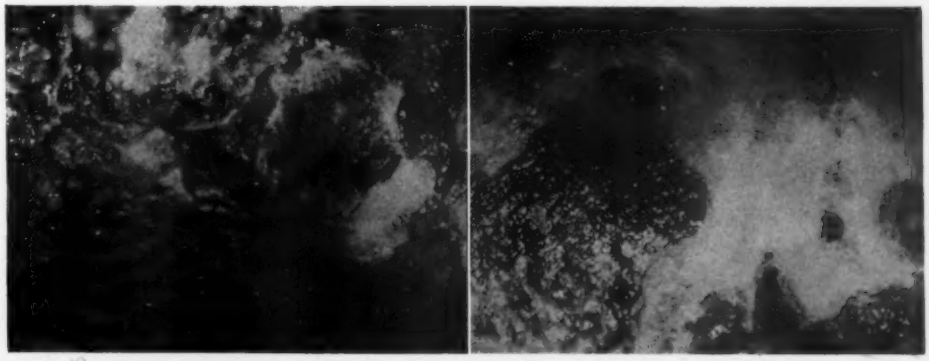
2A 2B

FIG. 2. A, Case 1, W. R. Initial application of homografts to thorax. B, Case 1, W. R. Initial application of homografts to lower abdomen and thighs.



3A 3B

FIG. 3. A, Case 1, W. R. Appearance of initial homografts at six weeks after application to thorax. B, appearance of initial homografts at six weeks after application to lower abdomen and thighs.



4A 4B

FIG. 4. A and B, Case 1, W. R. Appearance of homografted areas from seven to nine weeks after application. Note the cleanness of the burn area and the apparently reactionless melting away of the homografts.

5A 5B

FIG. 5. A and B, Case 1, W. R. Appearance of patient after discharge from hospital and nearly eight months post-burn.

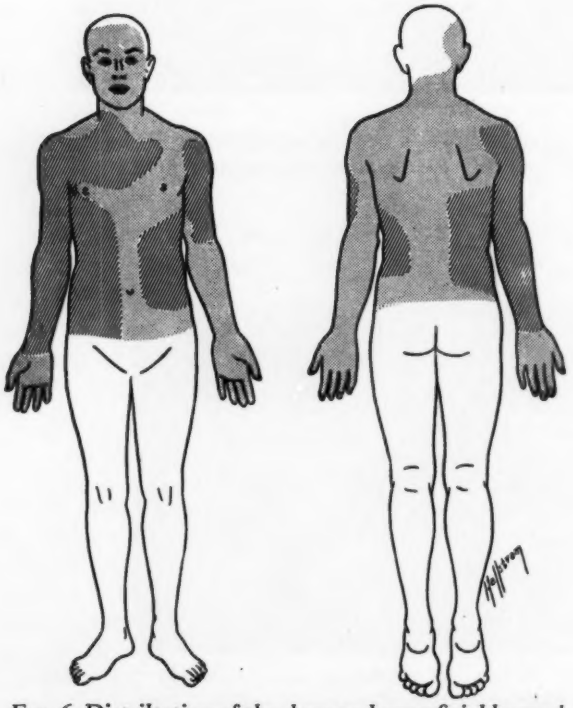


FIG. 6. Distribution of the deep and superficial burned areas in Case 11, patient E. F., thirteen years old. Shaded areas show extent of total burn. Dotted areas = superficial burn. Deep shaded areas = loss full thickness skin.

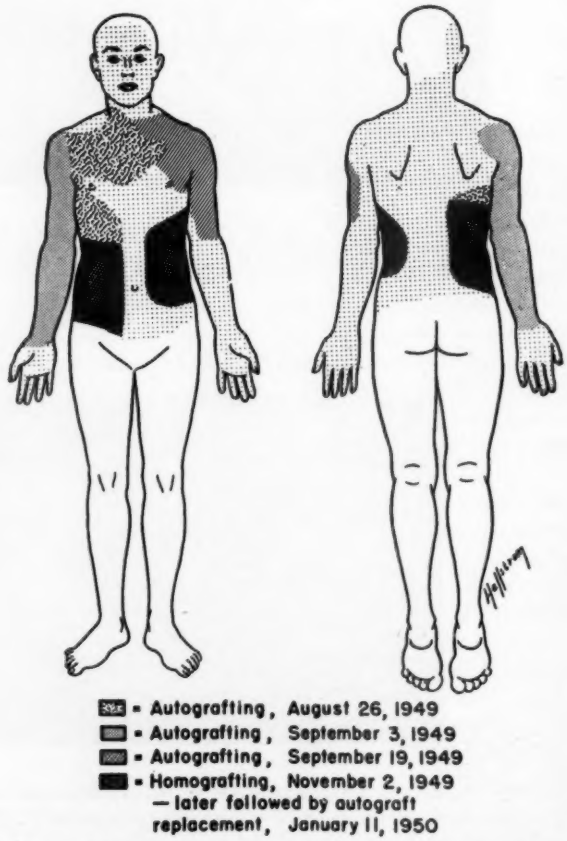

= Autografting, August 26, 1949
= Autografting, September 3, 1949
= Autografting, September 19, 1949
= Homografting, November 2, 1949
— later followed by autograft replacement, January 11, 1950

FIG. 7. Diagrammatic representation of the successive stages of autografting and homografting in Case 11, patient E. F.

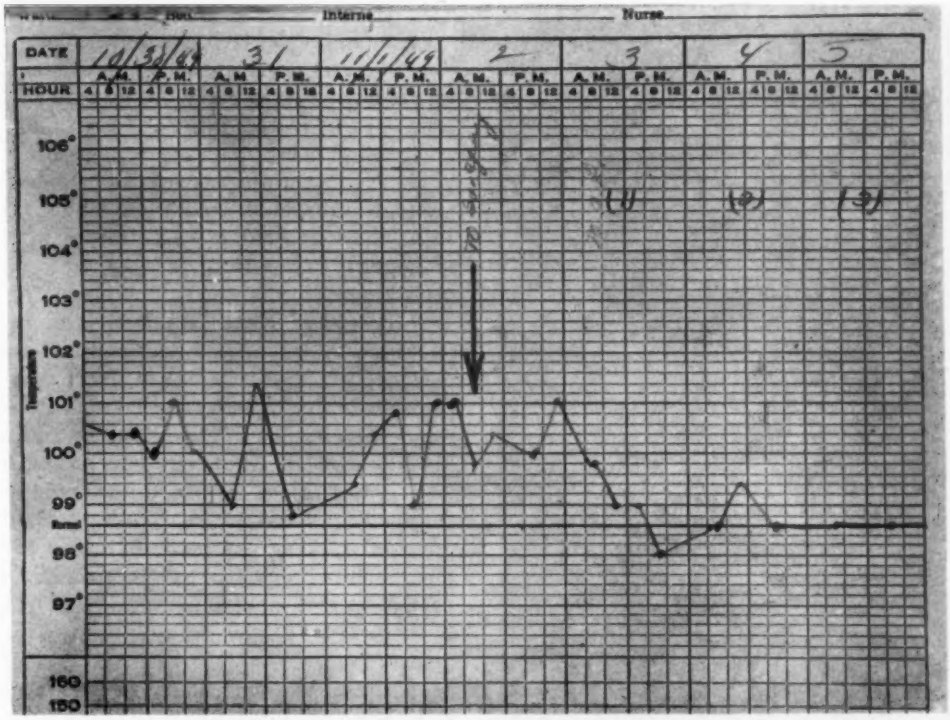
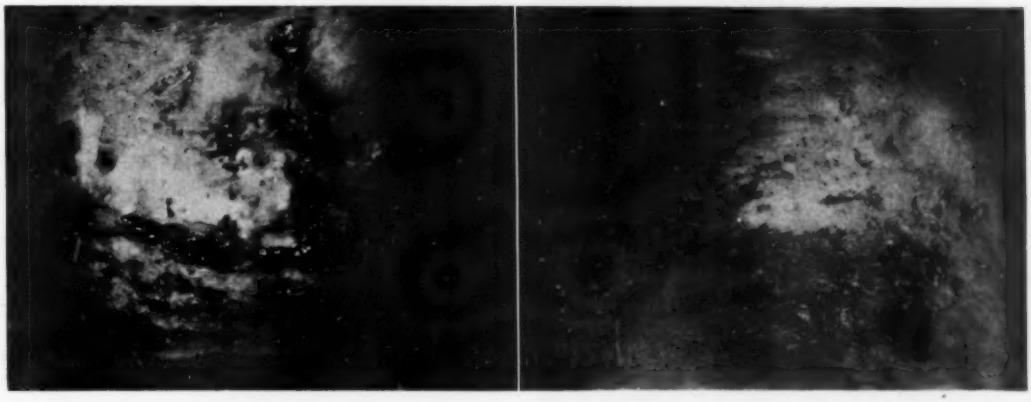


FIG. 8. Case II, E. F. Temperature chart showing prompt febrile to homografting. The temperature curve remained flat and normal until discharge, eighteen days later.

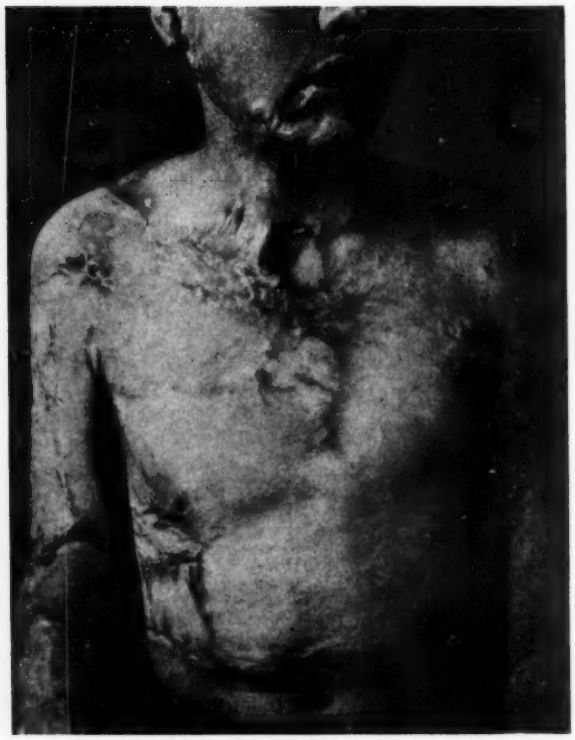


9A 9B

FIG. 9. Homografted area Case II, patient E. F., at seven weeks after application of homografts. A, right thorax; B, left thorax.

day intervals. All the homografts from both applications took extremely well and remained viable from six to eight weeks after application. (Fig. 3.) During this period the more lightly burned areas were healing; and by the time the first homografts began to melt, several areas were ready as donor sites for autografting. At seven-day intervals thereafter autografting procedures were carried out until all the areas of full thickness skin loss were covered withs the patient' own skin. It was possible to make such progress that some of the homografts were actually removed surgically to make room for the final application of autografts. (Fig. 4.) On March 4, 1950, four months post-burn, the patient was discharged from the hospital for morale purposes, with practically complete healing. (Fig. 5.)

CASE II. E. F., a thirteen year old white boy, suffered severe gasoline flame burns on August 9, 1949, resulting in a 60 per cent body surface burn, nearly one-half of which was full thickness in depth. The distribution of the burn is shown. (Fig. 6.) Within an hour of the receipt of the burn an occlusive sterile dressing of petrolatum gauze and machinist's waste had been applied in the hospital emergency room, and plasma had been started intravenously. During the next several hospital days his fluid requirements were met according to a modified Cope formula by the continuous intravenous administration, through



10A

10B

FIG. 10. A and B, Case 11, E. F. Condition of patient ten months post-burn with all areas healed and all homografted areas replaced with autogenous skin grafts. Obviously considerable reconstructive surgery will still be necessary to secure optimum cosmetic and functional results.

a polythene cannula, of plasma, whole blood and electrolyte solutions, supplemented by liberal oral intake of flavored electrolyte solution and fruit juices. Hourly urine output via a retention catheter was used to check the adequacy of the fluid ration.

The first formal burn dressing in the operating room was done on August 12th under light anesthesia, at which time a gentle partial débridement was done and a more efficient occlusive dressing (also of machinist's waste and petrolatum gauze) was applied. Similar débridement and dressings in the operating room but without anesthesia were carried out successively on August 15th, 17th and 22nd until the entire burned area had been gently relieved of necrotic tissue and gross dirt.

On August 26th, two weeks post-burn, with the patient in reasonably good physiological status, the right chest and axilla were grafted with thick split skin grafts taken from the patient's right thigh. A 50+ per cent take was achieved, and on September 3rd the entire right arm from and including the shoulder to and including the wrist was similarly grafted, grafts being taken from the left thigh. Again a better than 90 per cent take resulted, and on September 19th the left arm and a few open areas on the left chest were covered with thick split skin grafts taken from the now regenerated right thigh skin. A 100 per cent take resulted which left now only two areas on either side of the thorax uncovered. (Fig. 7.) The area on the right measured 12 by 10 inches, that on the left 6 by 8 inches. Dressings were now necessary only for these raw areas alone, all of the grafted areas being fully healed, and the patient completely ambulatory.

Although the boy was doing well physiologically, his morale was very bad; and it was thought that a brief respite at home with office dressings three times weekly would be helpful. He was discharged from the hospital on October 9th two months after the receipt of his burn. On October 23rd two weeks later, he suddenly lost his appetite, began to lose weight and became mildly jaundiced and febrile. He was readmitted to the hospital in which a tentative diagnosis of acute hepatitis was confirmed; the cephalin-cholesterol flocculation test was 4+ and the icterus index 13.7. It was believed that the two large granulating areas on his thorax, which were the same size as at discharge two weeks previously, constituted a severe protein leak which would interfere seriously with the therapy of his hepatitis. Because of the hepatitis, formal grafting under anesthesia would be somewhat hazardous. Consequently, on November 2, 1949, these areas were covered completely with six large homografts, taken under local anesthesia, from as many donors. No anesthesia was used for the patient, and the grafts were merely snubbed on by dressings. A complete take of the homografts resulted. The physiologic effects of the procedure were dramatic. The patient's fever dropped sharply. (Fig. 8.) His appetite improved sharply, and he began to gain weight. The icterus index dropped from 13.7 to 7.5 and the thymol turbidity from 8 to 3 units in two weeks' time. He was again discharged to his home clinically well on November 20th, with all areas healed.

Ten days after discharge from the hospital he was able to return to school, which he continued to

attend regularly until January 8, 1950, by which time the homografts were beginning to melt away and were exceedingly moth-eaten. (Fig. 9.)

On January 11th the remaining homografts were surgically débrided in the operating room and the resulting clean, fresh, raw areas were permanently covered with thick split skin grafts again taken from both thighs. A 100 per cent take resulted. The patient was discharged from the hospital on January 22nd. He has remained healed and well since, attending school regularly, doing his farm chores, and engaging in active competitive sports and the like without restriction. He was last seen on May 19, 1950, at which time he was growing, gaining weight and was extremely active and healthy. (Fig. 10.)

COMMENT

In Case I homografting answered the problem of life-saving surface coverage in a patient so extensively burned that skin for autografting was not available. In Case II homografting provided a physiologic plug to stop extensive protein leakage[17] in a patient whose acute hepatitis made nitrogen balance mandatory. Also, in this patient, for the same reasons, autografting would have been hazardous although sufficient donor skin was available.

In presenting these cases details of protein replacement, fluid balance, chemotherapy, physiotherapy and other supportive treatment have been purposely omitted with the implied understanding that all such measures were exhaustively used. In both cases the emphasis has been primarily on supportive therapy and prompt skin coverage to preserve life, realizing that optimal cosmetic and functional results must be temporarily postponed. Extensive reconstructive surgery will be required later on in both cases to correct scar tissue contractures, eliminate keloid and to improve bearing surfaces and cosmetic appearance.

A brief description of a few practical points in the homografting procedure would seem appropriate.

Selection of donors, we think, should be made with equal care as far as the absence of syphilis, malaria or infectious hepatitis is concerned, as in the case of blood donors. It is important as far as possible to rule out the presence of any abnormal bleeding tendency or sensitivity to novocain by specific questioning. Grafts are best cut under local infiltration anesthesia with 0.5% novocain, using a Pitkin continuous syringe for the infiltration which avoids the dermis and is aimed for the subcutaneous tissues. Infiltration of the former creates lumpiness in the donor site which interferes with cutting the graft. The entire donor area must be infiltrated. We prefer the thigh as donor site. Grafts may be cut either freehand or with one of the numerous graft-cutting devices available. The freehand method using the Blair-Brown knife and suction retractor is quickest and most efficient with limited assistance. It is well to have four teams for any extensive homografting procedure, namely, one to shave, prepare and drape the donor site; one to infiltrate the site with novocain; one to cut the graft and one to dress the donor site.

Alterations and combinations of the aforementioned plan may be made for short homografting procedures.

It is preferable, for good lay cooperation, to mantain the skin donors in as ambulatory a condition as possible, able to continue working and free enough from discomfort as not to prejudice themselves and others against future contributions of skin. This requires a good dressing of the donor site, well and carefully applied. We used two to three thicknesses of fine mesh scarlet red gauze, reenforced by several layers of gauze applied and fixed in place as described by Brown et al.[6] It is advisable to warn donors of the probability of red-staining of the dressing by the serum-moistened, scarlet red ointment so that they and friends and relatives will not suspect hemorrhage or disaster twenty-four hours later. We have found it advantageous to check each donor dressing in forty-eight hours to be sure that all is well.

In the twenty-eight homograft cutting operations described before no case of infection of the donor area occurred; all donors remained ambulatory and able to continue their jobs. Also, all donor sites were healed completely within fourteen days.

SUMMARY

Notwithstanding frequent reports attesting to the value of homografting, there is still a reluctance to use the procedure freely and early enough to realize its fullest benefits.[11,14,18] This is partly due no doubt to the knowledge that the surface covering obtained is temporary, plus a belief that the procedure is too troublesome and elaborate to be practical.

In our experience the ease of setting up on short notice a practical working scheme for homografting in surroundings that had never witnessed such a procedure before, the characteristically enthusiastic cooperation of the patient's friends and relatives who thereby gained a sense of participation in the task of getting the patient well and the immense sense of security given the surgeon by the possession of practically unlimited square inches of healthy skin in which to dress an extensively burned patient, make homografting seem to us a procedure of vast practical application and of particular common sense in the treatment of the acute extensive burn.

There is no more desolate situation than to bring a major burn case successfully through the first forty-eight hours or so of burn shock, edema formation and resolution, then to be confronted with a vast denuded area demanding prompt skin coverage and to wonder from where the skin is going to come. Homografting, we think, supplies the answer.

Despite firm conviction that early skin replacement is of paramount importance in the treatment of burns the tendency is strong and well nigh irresistible to wait weeks because of the poor condition of the patient, insufficient autogenous skin or a desire to be thrifty with what skin is left to the patient, and to use it only when a good take seems reasonably sure. All of these reasons for hesitancy spell delay, which may be fatal, and which can be circumvented by early recourse to homografting, a procedure which offers a generous supply of healthy skin at little or no physiologic expense to the patient and which can be undertaken to the great benefit of the sickest burn patient provided only that he be able to withstand the rigors of an extensive dressing.

The authors would like to suggest that the nearest approximation to the ideal dressing for severely burned skin is a healthy split skin graft, autogenous or homologous. They would like, also, to suggest that the initial formal dressing of an extensively and deeply burned patient might well be a skin dressing of homografts procured from relatives or friends during the first two or three days of burn treatment and stored under sterile conditions of optimum refrigeration until needed, which is as soon as the patient's shock and edema fluctuations are controlled and corrected.

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HUMAN BITES OF HEAD AND NECK*

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THERE is little published information concerning wounds of the head and neck caused by human bites. Attention has been directed mainly toward bites of the fingers and hands. Most human bites of the hands are actually dental injuries in which the fist is hit against the teeth resulting in a laceration of the skin and usually the tendon sheath and joint capsule. Upon opening the hand the tendon glides upward to carry contaminants with it. The severe crippling which results from infected hand wounds, along with subsequent amputations and occasional deaths, has been recognized for years. The organisms recovered from wound and blood cultures in these cases have included Staphylococcus aureus and albus, fusiform bacilli, spirochetes, Spirillum of Vincent and streptococci of various types including the anaerobic in symbiosis with other organisms as mentioned by Meleney.

For the most part human bites of the face differ from hand bites in that they are not dental injuries. They are true bites frequently associated with loss of tissue. About 80 per cent of all human bite lacerations involve the fingers and hands while the remaining 20 per cent are scattered over the rest of the body. In the literature treatment of human bites of the face is usually discussed in conjunction with and secondarily to that of the hands.

A brief review will demonstrate the attitude toward the care of lesions resulting from human bites. Mason and Koch in 1930 outlined a treatment for bites of the hands which consists of washing, irrigation, débridement and immobilization. In 1931, 199 cases of human bites treated with electrocautery were discussed by William Bates. No mention was made regarding specific management of those of the head and neck and it must be assumed that all bite wounds received similar treatment regardless of location. Laurie in 1936 presented 122 cases of human bites. Ten or 8 per cent involved the head and neck. Both the hand wounds and face wounds were treated with nitric acid followed with wet dressings. In 1939 a single case of a human bite laceration of the eyelids was reported by Sniderman. The wound was cleansed and primarily sutured, with prompt healing. Boland in 1941 reported twenty-four of sixty human bites to have resulted in facial wounds.

TABLE 1
BITES OF HEAD AND NECK*

Treatment	No. of Cases	Results
Soap, water.....	12	Remained clean
Soap, water.....	6	Inflammation without suppuration
Soap, water, sutured.....	11	Healed
Soap, water, sutured.....	2	Healed; inflammation without suppuration
Soap, water, phenol, alcohol.....	5	Clean
Phenol, alcohol....	2	Clean

* (A portion of table from SPIERS, RICHARD E. *Surg., Gynec. & Obst.*, 72: 619–621, 1941.)

His paper was mainly a discussion of the hand wounds. Concerning bites elsewhere on the body he stated that they " . . . produced only symptoms such as would follow an ordinary abrasion or laceration." In 1941 Spiers reported a series of human bites, thirty-eight of which involved the head and neck. This again was primarily a discussion of bites of the hands. The results of treatment of the head and neck injuries are tabulated in Table 1. Ninety-one cases were discussed by Boyce in 1942. Eighteen involved areas other than the hands and these were said to have presented few complications.

In general, emphasis has been on the treatment of human bites of the hands. It is probable that the same treatment is being applied to those of the head and neck. The aim of this paper is to focus attention on human bites of the face. For this purpose we have reviewed the

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cases of those patients admitted to the City of Detroit Receiving Hospital from 1942 to 1949 because of human bites of the head and neck. There were forty-six patients.

The age, sex and race are of little consequence. The circumstances leading to the bites

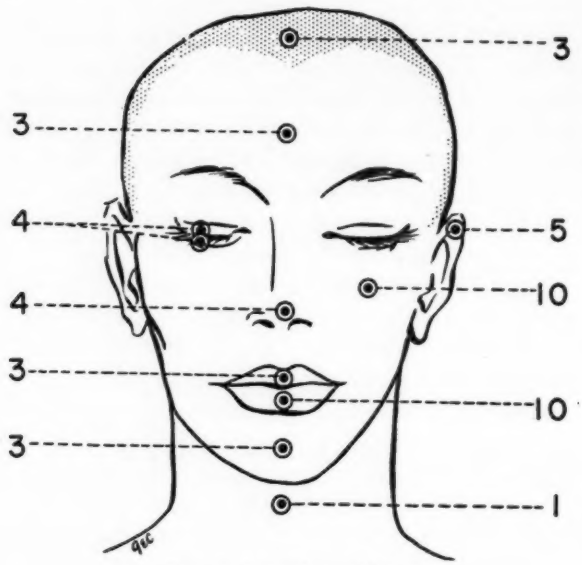


FIG. 1. Location of bites.

are of some interest. Thirty-three were recorded as having occurred in fights, six were accidentally sustained by children at play and two resulted from sexual attack. The cause in five could not be determined. Location of the bites is demonstrated in Figure 1. The cheeks and lower lip were involved most frequently. There

FIG. 2. Three-day old infected human bite of the lower lip photographed eight weeks later; note the bulging of the lip and the uneven vermilion border.

was loss of tissue in one of the cheek bites and in seven of the lower lip bites.

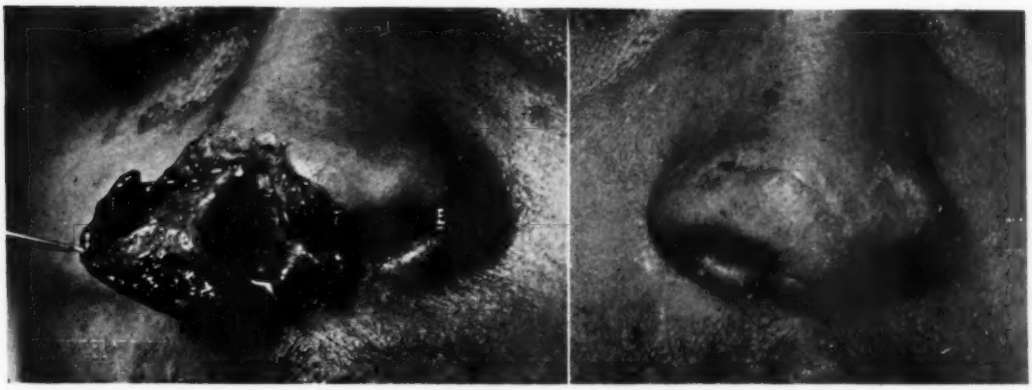
The average hospital stay was 5.78 days. There were no fatalities. It is interesting that twenty-two patients received tetanus antitoxin. Lowry has pointed out that this is unnecessary because tetanus bacilli have never been found in the human mouth and no case of tetanus has been reported following a human bite.

For comparative study the forty-six cases are divided into three groups as follows: Group I, wounds infected at the time of admission; Group II, fresh wounds not sutured; and Group III, fresh wounds sutured. In the first group evidence of infection varied from edema and serous drainage to cellulitis and frank pus. The shortest elapsed time from the bite to the time of

TABLE II

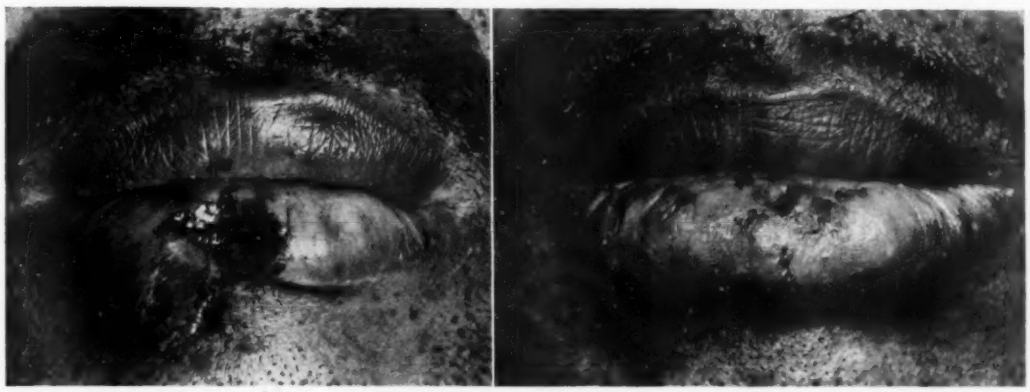
HUMAN BITES OF HEAD AND NECK

Type	No. of Cases	Average Hospital Da.	Temperature				Chemotherapy				Treatment	Results
			98.6°F.	100°F.	Over	No Record	Penicillin	Sulfa	Penicillin and Sulfa	None		
Group I Infected.....	20	6.1	5	7	5	3	8	5	2	5	Soaked	19 clean and granulating; 1 secondarily repaired
Group II Fresh wounds not sutured.	13	5.8	4	5	0	4	7	1	0	5	Washed; débrided; soaked	All clean and granulating
Group III Fresh wounds sutured....	13	5.6	4	6	2	1	1	11	0	1	Washed; débrided; sutured	11 primarily healed; 2 infected (1 without suppuration)



3A 3B

FIG. 3. A, human bite of the nose five hours old; B, same patient photographed seven days after primary débridement and suturing.



4A 4B

FIG. 4. A, fresh human bite of the lip two hours after occurrence; B, photographed eight days after primary débridement and repair.

admission was fourteen hours and the longest fifteen days, averaging three days. The second and third groups include the fresh wounds without evidence of infection. There was no consistent plan of management of these fresh wounds and the therapy instituted bore no relation to the extent or location of the bite laceration. Rather it depended on the interest, judgment and inclination of the various surgical residents on the admitting service. It can be seen that the treatment of fresh wounds not primarily sutured reflects the accepted management of human bites of the hands whereas the sutured lacerations have been treated as facial lacerations from other causes.

There were twenty cases in Group I (Table II) and thirteen in each of the other two groups. The hospital days averaged 6.1, 5.8 and 5.6. In seven cases the highest temperature was over 100°F. Five of these were in the infected group. The other two were in the primarily sutured group, one patient having a frankly purulent wound and the other inflammation without suppuration. Lymph nodes were palpable in four patients and these were all in the infected group.

Five patients in each of the first two groups and one in the third group received no chemotherapy. All the others, a total of thirty-five, received either a sulfonamide drug or penicillin. Two patients received a combination of the drugs.

The wounds infected at the time of admission were treated with continuous wet applications. The fresh wounds not sutured were also treated with continuous wet dressings after preliminary débridement had been accomplished as indicated. All the wounds which were sutured immediately were washed for ten minutes with soap and water, followed with débridement and suturing under local or regional block anesthesia.

At the time of discharge from the hospital nineteen of twenty wounds in Group I were

clean and granulating. One wound had been secondarily repaired and was well healed. All thirteen wounds in the second group were clean and granulating at the time of discharge. No attempt had been made to close these wounds with a secondary procedure. Therefore, a high percentage of the patients in both these groups, depending on the extent of the laceration or defect, will need a cosmetic procedure at a later date. (Fig. 2.) Although there was a varying amount of edema for the first twenty-four to forty-eight hours in the primary repair group, twelve of the thirteen wounds healed by first intention and were cosmetically satisfactory upon discharge from the hospital. (Figs. 3 and 4.) As previously mentioned one wound became purulent. It was opened and packed; at the time of the patient's discharge from the hospital this wound was similar to a fresh wound not sutured.

The conclusions we wish to draw from this review are as follows: (1) Wounds of the face resulting from human bites, even though infected, are not as severe or disabling as those of the hands. (2) Lacerations and tissue defects resulting from human bites of the head and neck can be safely treated as facial lacerations from other causes. (3) The reason for the difference in the pathology and in the treatment of human bites of the hands and facial bite wounds appears to be anatomic.

Addendum. Since this paper was prepared, six additional fresh human bites of the face have been treated. Two involved the lower lip, two the nose, one the ear and one the forehead. This brings the total to fifty-two cases. All of the added six cases were cleaned, débrided and initially repaired. Two patients were hospitalized and the other four received penicillin and follow-up care in the outpatient clinic.

One wound, a bite of the forehead, became infected. Five wounds were cosmetically satisfactory. The most recent patient suffered a loss of the entire tip of the nose including the columella. He was treated primarily with débridement and attachment of a pedicle flap from the upper arm.

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PLANNED TIMING IN TREATMENT OF CHRONIC OSTEOMYELITIS UNDER ANTIBIOTIC CONTROL

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THE objective in the treatment of chronic osteomyelitis is the arrest and elimination of active foci with an expectancy of permanent healing under a closed wound, with the least resulting deformity in the shortest period of time. To meet this objective we must have comprehensive knowledge of the origin, the processes of destruction, reasons of recurrence and foundation of resistance in order to establish principles for the arrest, control and repair of this condition.

In this evaluation it has become apparent that the basic principle of repair of defects in infected bone lesions such as chronic osteitis and osteomyelitis under antibiotic prophylaxis and control is that only with sufficient care in such procedures and sufficient respect for essential details may a high percentage of recovery be expected. Especially is this so in a preanticipated schedule with a reasonable expectancy of wound-healing.

Improved surgical management of traumatic wounds in civilian and military life together with the judicious use of potent antibiotics has reduced greatly the incidence of post-traumatic osteomyelitis in the hospital. Nevertheless, these patients continue to be seen in all general hospitals and many present a challenge to even the most experienced of surgeons.

That the treatment of this condition demands patience from both the surgeon and patient is evidenced by the fact that the average stay in hospitals may be many months. This is the case particularly in government hospitals where the patient must be kept in the hospital until he has received maximal benefits of treatment. Although no new principles for the treatment of osteomyelitis have been discovered recently, it would seem there is a need for greater diffusion of knowledge as to what constitutes adequate operation and what is considered proper timing for completion of the steps necessary for bringing the wound resulting from operation to a permanently closed system. Basically the steps comprising treatment of osteomyelitis include preparation of the patient for surgery, eradication of bacteria-laden compromised tissue, provision of adequate blood supply, reinforcement of bone where necessary to provide a functioning limb and full skin-thickness cover.

Preparation of the Patient. This entails simultaneous concentration on the patient as a whole and on his disease complex. Attention is directed early to correction of blood and protein deficiency, well known deterrents to recovery from infection, and to good wound-healing. Characteristically chronic suppurative disease is accompanied with anemia and hypoproteinemia, with a shrunken circulating blood value which is frequently masked by normal hemoglobin and total blood protein values. Wherever facilities are available repeated quantitative blood volume determinations by Evans' blue dye or tagged ion methods are most accurate criteria of the blood and protein needs of the patient than by hematocrit, hemoglobin and plasma protein determinations. Where such facilities are not available, blood and plasma transfusions followed with frequent hematocrit readings are useful for gauging additional blood and plasma requirements. When a hematocrit of 50 is sustained after blood transfusion, the cardiovascular tree is filled and replacement therapy is then considered adequate. No change in the hematocrit reading after transfusion indicates the vascular tree is not filled and additional replacement is necessary.

Preparation of the Limb. Preparation of the limb for surgery begins with estimation of adequacy of peripheral circulation of the extremity. Prolonged immobilization or disuse of an extremity contributes to diminution of the blood supply and a cold limb. Lumbar sympathetic blocks often result in improvement in circulation of the extremity and are beneficial in bringing about conditions favorable to wound-healing.

The wound itself is given detailed study. Roentgenograms in several planes, with contrast media injected through the fistulous tract if necessary, assist in visualization of the path of fistula connecting surface with bone, location of sequestra and estimation of the extent of pathologically altered bone. The soft parts are critically appraised so that the scheme for excision of scar tissue will encompass a solution to the problem of providing muscle pedicle filling of the bony defect if indicated and, most importantly, of providing full-thickness cover. Full-thickness cover is often the keystone to successful management in chronic osteomyelitis. Due consideration is given to improvement of local hygiene. The skin surrounding the fistula is brought to a condition of as near normalcy as possible by elimination of maceration and dermatitis. Whenever drainage is profuse, dressings are changed at frequent intervals. The limb is bathed at least twice a day for three days before surgery with G-11 compound in soap or cream base. We neither employ nor recommend the use of antiseptics or antibiotics around or in the wound because their efficacy is questioned and the danger of inducing sensitization is great.

The bacterial flora of the wound exudate are determined and culture sensitivity tests are made. Although there are several methods for determining culture sensitivity, the agar plate-medicated disc method is simplest. It consists of the application to freshly seeded blood agar plates discs containing measured amounts of each antibiotic. Premedicated discs are now or shortly will be commercially available. Zones of inhibition can be read after twelve to eighteen hours of incubation in most instances. Spot sensitivity determinations with several test organisms show close correlation with corresponding tube sensitivities. Culture sensitivity data provide information not only concerning the probable drug of choice and the possible alternative agents but also a clue as to the dosage required. In chronic osteomyelitis the wound flora is more apt to be heterogenous than monobacterial, with proteus, pyocyaneus or coliform bacteria prominent. The mixtures notwithstanding, bacteria in wounds capable of producing invasive infection are the hemolytic staphylococcus aureus, hemolytic streptococcus and the toxigenic clostridia. About 60 per cent of staphylococci isolated by us are penicillin-sensitive while nearly 80 per cent of hemolytic streptococci are penicillin-sensitive. Penicillin-resistant cocci are penicillinase producers as are coliform bacteria, proteus and pseudomonas. For these two reasons we prefer now to employ the newer, broader spectrum antibiotics, aureomycin, terramycin or chloromycetin, alone or combined with penicillin. We prefer chloromycetin with or without penicillin because it is highly effective against cocci and therapeutically active on many strains of proteus and pyocyaneus. In the ordinary case antibiotics in full doses are begun the day before operation so as to perfuse the tissues freely with a blood-borne drug, and are continued for five to seven days postoperatively. Topical applications, it is reiterated, are not employed routinely and are reserved for the exceptional case.

Postoperatively, cultures are again made to aid and abet clinical appraisal of the thoroughness with which compromised tissue capable of perpetuating infection has been removed. Persistence of invasive bacteria postoperatively warrants delay in further surgery until the cause for this persistence has been determined and removed.

In summary, the patient is ready for surgery of chronic osteomyelitis of long bones when the nutritional, blood and protein deficiencies have been corrected, circulation of the limb has been brought to optimal efficiency, type and extent of scar and bony damage has been determined clinically and roentgenologically, causal bacteria have been identified, antibiotic culture sensitivity tested and held against invasion by trauma into contiguous structures and, finally, plans have been formulated for providing all-important early full skin cover and indicated filling of the bony defect.

When the wound site is ready for closure, the choice of muscle or bone to be used in filling the defect must be made. Transposed muscle must have a pedicle for its blood supply. To obtain this muscle a strip sufficient to fill the cavity is separated from its parent in its long axis and divided distally with sufficient length to be transposed and fixed into its new bed without tension; or chips of cancellous bone sufficient to fill a cavity are obtained from a section of the iliac crest or bone bank of cancellous bone and chopped into pea-sized chips which are snugly packed into the cavity. According to the depth, size, location and position of the wound the timing for and method of closure of the wound is to be determined.

If the lesion is in the femur, there is practically always sufficient muscle and skin to fill or cover a bone cavity of any size. Particularly is this true above the condylar expansion where ample muscle may be transposed with a good blood supply. The tibia, however, presents a different problem which at times requires all the ingenuity and judgment we may possess. Muscle may be transposed only in the middle third which may be only from a section of the anterior tibial muscle. Above that area it must be reversed on its pedicle with only a poor blood supply if it is to be inserted into the upper one-third of the tibia, and it is much too fibrous to use in the lower one-third of the shaft.

The covering of tibial defects with full-thickness skin is one of our most serious problems and will always remain a *sine qua non* of success. Transposed muscle or bone into a bone cavity must be covered with living tissue or else it dies. This is so because there is never sufficient supportive blood supply to be derived from a tibial cortex or refilled cavity to support and maintain life in unattached skin whether it is split-thickness or whole-thickness. To live a blood supply must be transposed with the skin and this part of the problem must be figured out and decided upon before other steps of closure are undertaken. Otherwise, the procedure from the beginning will be to follow the older plan of closure by granular filling from the bottom of the wound and coverage by fibrosis and dermatization or split or pinch graft.

The preparation of these covering flaps when determined upon should be begun one to three weeks before they are needed to insure their active viability with the source of their blood supply and its expectancy reasonably known. Our procedure is to decide whether the flap may be slid across the defect and attached to the skin on the opposite side and so retain its proximal and distal attachments or is to be freed from its distal attachment or be brought from above by a reversed tubular transfer. When this is decided upon and the cavity ready, we prefer first to transfer and suture this flap in place over a vaseline pack to test its viability for five to seven days and then reopen the wound, remove the pack and fill the cavity with bone or muscle as previously determined and resuture this living flap to its bed. The defect from which it came is covered with split-thickness skin.

This elaborate preparation will be wasted if it does not culminate in good surgery. There can be no compromise with the principle of thorough, complete excision of all devitalized tissue. Half-hearted efforts always lead to repetition of infection and extension of necrosis. Removal of diseased tissues as well as bone is most easily effected in a dry field which is secured by the use of a tourniquet. We have been using the tourniquet almost routinely without evidence of spreading infection or of circulatory complications ensuing. In addition, blood loss is kept to a minimum.

Finally, it is our considered opinion that the personal attention given by the surgeon postoperatively to details of care are as important as the operation itself. Constant observation by the operator, not his junior staff, during the evolution of the lesion postoperatively will often result in the discovery of small devitalized areas about which the operator may have felt insecure at the time of surgery, with the result that time and effort are saved by getting at these early. Continuity of effort by the same surgeon is the best insurance for a successful campaign of attack on the lesion.

TRAUMA TO THE PERINEUM, ANUS, RECTUM AND COLON*

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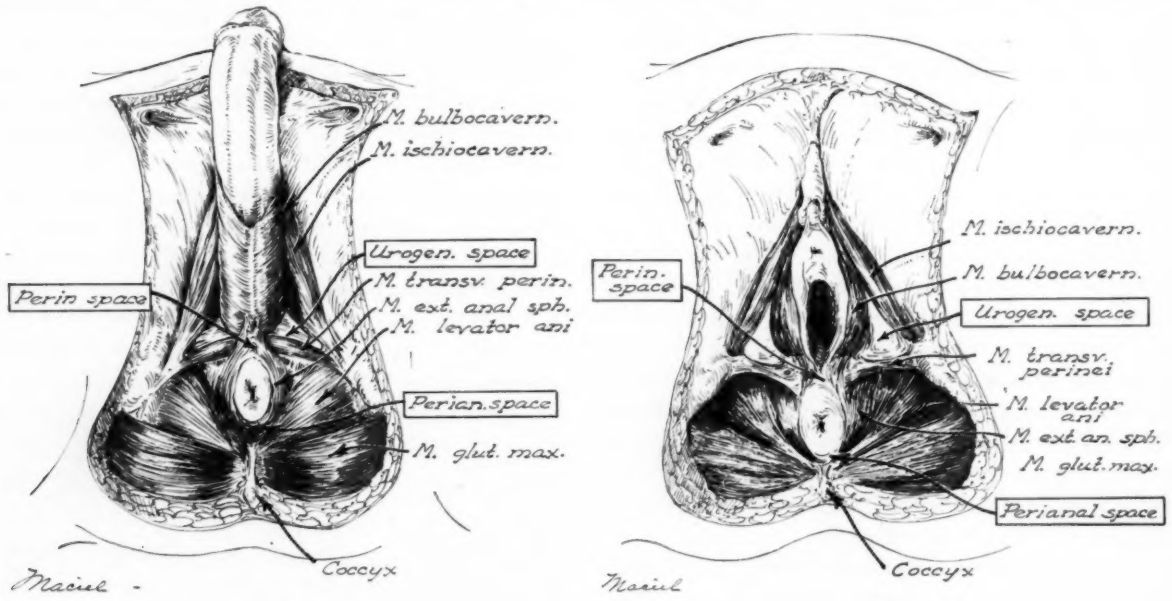
ALTHOUGH wounds of violence to the perineum, anus, rectum and colon occur infrequently, the management of patients with wounds in this region poses many serious problems to the general surgeon. Furthermore, many of these injuries might appear trivial when first seen by the physician and definitive treatment therefore delayed, with the result that the life of the patient is endangered. We wish to discuss the bizarre types of injury due to violence in relationship to the anatomic structures and to emphasize some of the important surgical principles which underlie their care. In order to develop a clear concept of the problem the anatomy of the perineum, anus, rectum and sigmoid colon is reviewed.



IA IB

FIG. 1. A, anatomy of male perineum; B, anatomy of female perineum.

ANATOMY

Perineum. The perineum is a lozenge-shaped area, the pelvic outlet, being bounded anteriorly by the pubic arch and arcuate ligament, posteriorly by the tip of the coccyx, and laterally on each side by the inferior rami of the pubis and ischium and the sacrotuberous ligament. By drawing a line transversely across in front of the ischial tuberosities the perineum is divided into an anterior area, the urogenital region, and a posterior area, the anal region. These two anatomic points justify a discussion of the two regions in relation to sex.

In the urogenital region in the male (Fig. 1A), immediately under the skin is the superficial fascia, the outer layer of which contains fat and areolar tissue. In the middle line it is adherent to the skin and the deep layer of the superficial fascia described by Colles. This deep layer serves to bind down the muscles of the root of the penis, being continuous with the tunica dartos, deep fascia of the penis, fascia of the spermatic cord and Scarpa's fascia upon the anterior abdominal wall. Laterally

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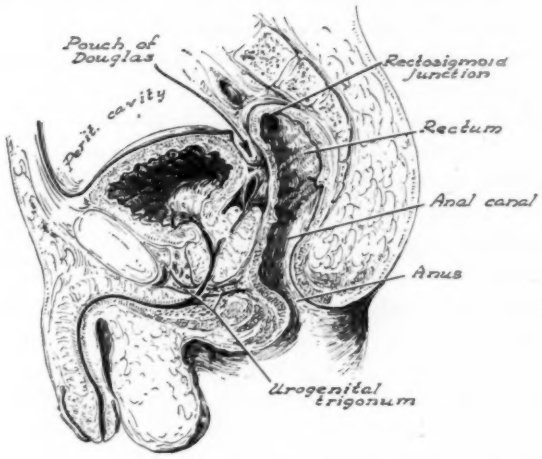
it is fixed to the pubis and ischium and posteriorly it joins the inferior fascia of the urogenital diaphragm. This fascia covers all the muscles of this region. The central tendinous portion of the middle line of the perineum lies between the urethra and anus. At this point six muscles are attached, namely, the external anal sphincter, the bulbocavernosus, the two superficial transverse perineal muscles and the anterior fibers of the two levatores ani.

The superficial muscles in this region are the superficial transverse perineal muscles, the bulbocavernosus and the ischiocavernosus, all of which are closely related to the functions of the penis.

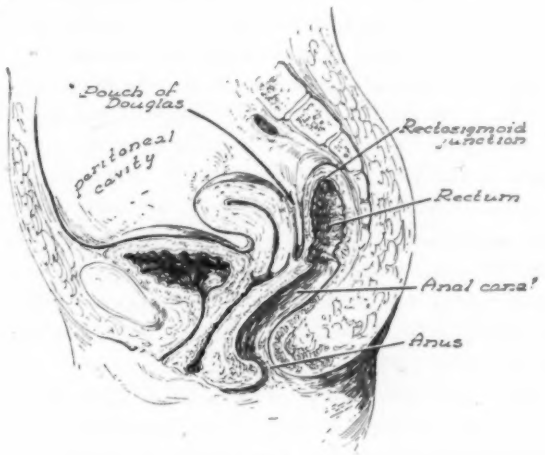
The deep fascia of this region covers two important muscles, namely, the sphincter urethrae membranaceae (surrounding the entire length of the urethra) and the transversus perinei profundus which lies posterior to the former muscle but in the same plane. The fascia, in congress with the muscles, is known as the urogenital diaphragm or triangular ligament. Within these structures lie the deep vessels and nerves, the internal pudendal artery and vein and the pudendal nerve.

The urogenital region in the female is comparable to that in the male except for the distinct differences in the pelvic outlet. (Fig. 1B.) The vaginal orifice and canal are extremely close to the anal canal and rectum. The superficial fascia remains exactly as in the male, covering the superficial transversus perinei, the bulbocavernosus and the ischiocavernosus muscles, all of which have functions similar to the male anatomy.

The deep fascia of the female perineum (urogenital diaphragm) is not as well developed as in the male. It consists of two layers between which are incorporated the transversus perinei profundus and the sphincter urethrae membranaceae. In this structure are the deep arteries, veins and nerves, branches of the internal pudendal vessels and the pudendal nerve, respectively.



2A



2B

FIG. 2. A, sagittal section showing anatomy of anus, rectum and colon in relationship to the pelvic structures in the male; B, sagittal section showing anatomy of anus, rectum and colon in relationship to the pelvic structures in the female.

Anal Region. The anal region (Figs. 2A and B) is the posterior area of the perineum which contains the termination of the anal canal. The anus is supported by a superficial fascia which is very thick and contains much fat. On each side a fatty pad extends deeply between the levator ani and the obturator internus into a space known as the ischiorectal fossa. The lining of this fossa is formed by the deep fascia which envelopes the fatty tissue. This space also contains the inferior hemorrhoidal vessels and nerves, the pudendal plexus and the scrotal or labial vessels. In Alcock's canal on the lateral side of the fossa lie the internal pudendal vessels and pudendal nerve. The important muscles of the anus are the corrugator cutis ani, sphincter ani externus and sphincter ani internus.

The anal canal or terminal portion of the large intestine begins at the level of the prostate and ends at the anus. It has no peritoneal covering but is invested by the internal anal

sphincter, supported by the levatores ani and surrounded at its termination by the external anal sphincter.

Rectum and Sigmoid Colon. The rectum is continuous with the sigmoid colon above while below it ends in the anal canal. (Figs. 2A and B.) From its origin at the level of the third sacral vertebra it passes inferiorly for a distance of about 12 cm. Near its termination there is dilatation to form the rectal ampulla.

The peritoneum covers the upper two-thirds of the rectum, at first the front and sides, more inferiorly only the front, and finally it passes over onto the seminal vesicles in the male and posterior vaginal wall in the female. The rectum is surrounded by a dense tube of fascia derived from the endopelvic fascia but fused behind with the fascia covering the sacrum and coccyx.

The sigmoid colon, the terminal portion of the descending colon, forms a loop which averages about 40 cm. in length and normally lies within the pelvis. It is completely surrounded by peritoneum which forms its mesentery thus permitting mobility of this structure. Posterior to the sigmoid colon is the left sacral plexus of nerves. Anteriorly it is separated from the bladder in the male, and the uterus in the female, by coils of small intestine.

TYPES OF VIOLENCE

From this anatomic survey realization of the seriousness of violence to this region becomes apparent. Essentially there are two types of violence to this region: direct and indirect.

Direct violence occurs more frequently than does indirect violence. The implements of trauma have been numerous and bizarre, ranging from pieces of wood and limbs of trees or bushes to various metal objects including pickets of iron fences, shrapnel and bullets. Children sustain injury to this region by sliding down banisters and playground slides, slipping on tree trunks while climbing and from falling on or straddling fences. Less frequently such injuries occur while a person is in the act of sitting. Unfortunately, the improper administration of enemas, using a hard rubber nozzle, has produced perforation of the rectum and rectovaginal septum. A review of the literature[1–31] reveals the experiences of many observers regarding this type of injury.

Obviously the magnitude of such injury depends on the physical properties of the implement of trauma and the location and depth of its penetration. Wounds resulting from such violence may range from simple lacerations or abrasions of the perineal skin to contused, jagged, penetrating wounds of the urogenital region, anus, rectum, sigmoid colon and closely related intraperitoneal viscera. Experiences in World War II regarding gunshot wounds in this region clearly demonstrate their seriousness and the difficulties of obtaining successful repair without prolonged complications.

A practical viewpoint suggests that there are five important anatomic sites of involvement from deep penetrating wounds, each of which warrants some comment. (Figs. 2A and B.)

1. Urogenital region: Deep lacerations or deep penetrating wounds in the urogenital region are usually indicative of periurethral, urethral or bladder damage. Suspicion of injury to these vital organs will lead to proper diagnostic methods, urinalysis, urethral catheterization, cystoscopy and cystography when indicated.

2. Anal region: In the anal region more serious injuries consist of complete division of the anal sphincters. The perianal space has been contaminated and correct therapy may loom as a distinct problem.

Among the five cardinal anatomic sites the two most important areas are the ischiorectal fossa and the infrapelvic retroperitoneal space. Perforation of the rectum giving rise to contamination and infection in either of these potential spaces can be overlooked when patients are first seen following injury. Wounds of the urogenital and anal regions are obvious and signs of peritoneal irritation suggest intraperitoneal perforation of the large bowel or other viscera. The ischiorectal fossa and the infrapelvic retroperitoneal space are the silent regions. Correct diagnosis of the injury should be made by digital and proctoscopic examination. *Proctosigmoidoscopy is imperative in every patient with a history of injury to this region.*

3. Ischiorectal fossa: Wounds in the ischiorectal fossa have serious implications which may lead to sequellae of long morbidity and, occasionally, death of the patient. Injury may result from perforation of the rectum or penetrating wounds may occur directly into

the space without involvement of the lower alimentary tract. In either instance a mixed bacterial infection may result, producing inflammation in fatty tissue deficient in blood supply, and non-resistant to spread of infection, which without proper treatment may result in an ischiorectal abscess and it in turn may produce complications not generally considered possible.

4. Retroperitoneal infrapelvic space: Injury to this potential space is generally the result of deep penetration of a bullet or other foreign object. The rectal wall is perforated and contamination of this area is immediate. Bacterial growth may be rapid and a spreading, dissecting infection in the extraperitoneal space can quickly endanger life. Spreading abscesses have been noted to extend to the layers of the anterior abdominal wall, posteriorly to the sacrum, inferiorly to the muscle planes of the thigh, and, on occasions, a few have ruptured into the peritoneal cavity resulting in generalized peritonitis and death. These infections frequently are symbiotic in behavior. Bacterial culture may show numerous organisms including the Clostridium welchii group.

5. Pelvis or peritoneal cavity: Deep penetration by solid objects such as bullets, proctoscopes and other instruments have produced perforation of the rectum and/or sigmoid colon, giving rise to generalized peritonitis of varying degrees. Associated damage to the bladder (the prostate and the seminal vesicles in the male and the uterus in the female) may or may not conceal evidence of early generalized peritonitis. In such an instance the extent of damage frequently cannot be determined until after surgical exploration of the pelvis and the wound to demonstrate clearly all the structures that have been involved. Unquestionably, extensive injury of this type requires close preoperative observation and correct surgical treatment if rapid recovery with minimal complications is to be expected.

Indirect violence is usually the result of sudden dilatation of the bowel by compressed air. Andrews[32] and other observers[33–38] have discussed this type of injury. Industrial workers use compressed air to clean their trousers and perforation of the colon has occurred by a sudden blast of air in the region of the perineum. The nozzle need not be against the anus nor even directed toward it to produce such an injury. These accidents have resulted when compressed air has been used by a practical joker to scare a fellow worker. Perforation of the bowel usually occurs at or above the rectosigmoid junction. With this type of perforation pneumoperitoneum develops, causing marked abdominal distention with sudden severe state of peripheral circulatory collapse and frequently unconsciousness. In such instances the history is important in establishing the correct diagnosis.

TREATMENT

All injuries about the perineum, anus, rectum and colon warrant good first-aid management. A clean dressing covering the perineum and held by any type of perineal binder is advocated. Patients with wounds in this region should be admitted to a hospital where facilities are available for complete diagnosis and surgical treatment.

The history of the nature and extent of injury should not be minimized. General physical examination reveals factors of importance such as the degree of peripheral circulatory collapse, blood loss and the possibility of intraperitoneal involvement. The fact that there are no signs of external injury does not preclude the possibility of injury to the rectum or colon whether the violence has been direct or indirect. Attempt is made to determine the extent of injury in terms of normal anatomy and, if possible, to decide early whether surgical treatment is to be confined to a perineal approach alone, an abdominal approach alone, or a combination of the two. There can be little criticism to the general principle that abdominal exploration is indicated when there is the slightest evidence of perforation in the rectum or colon.

Urinalysis following catheterization will usually show whether there is injury of the urethra and/or the bladder.

Inspection, rectal examination and proctosigmoidoscopy will in most cases lead to a correct diagnosis of perforation of the lower part of the large bowel. Emphasis must be placed on the fact that pneumatic perforations from compressed air may occur in the descending colon beyond the view of the sigmoidoscope. Pneumoperitoneum may be diagnosed by clinical signs and/or roentgenograms.

Preoperative Treatment. Peripheral circulatory collapse should be treated immediately

with supportive measures. Whole blood should be administered early, particularly if there has been hemorrhage. The respiratory tract should be studied carefully to insure proper exchange of air and absence of injury to the thorax and lungs. Antibiotic therapy should be started immediately, giving large doses of penicillin (400,000 units), streptomycin (1 gm.) and sulfadiazine (2½ gm. to 5 gm. intravenously) as initial doses. Adequate levels should be maintained. Antitetanus therapy is important since it is well known that tetanus infection frequently results from such injuries to the bowel. In case of any injury to the urethra and/or the bladder an indwelling catheter should be placed and left in position until the proper time for its removal. Operative treatment should be delayed until the status of any given patient justifies anesthesia without added risk.

Operative Treatment. If preoperative diagnosis indicates a perineal approach only, the wounds usually are limited to simple lacerations of the perineum. Perforations or possible perforations of the rectum and colon should not be approached by this route alone. For proper emphasis on operative treatment the five cardinal anatomic areas are considered:

1. Urogenital region: Laceration of the urethra should be repaired using No. 4-0 chromic catgut after proper cleansing and débridement of the wound. Urethral splint using a catheter plus suprapubic cystostomy has the general acceptance of urologic practice.

2. Anal region: Severance of the anal sphincters should be repaired and the extent of injury must be the factor by which the doctor determines whether temporary colostomy should be instituted. The perianal space is usually drained. During convalescence voluntary sphincter exercises with sphincter dilatation may help tremendously in obtaining a good functional result.

3. Ischiorectal region: Puncture wounds into the ischiorectal fossa with damage to the levator ani but without perforation or injury to the rectum or urethra should be explored by careful dissection. The wound should be cleansed, foreign bodies removed, necrotic tissue excised and anatomic repair accomplished with drainage of the fossa.

When the rectum has been perforated, the defect should be repaired. The perforation can often be approached with coccygectomy alone, or exposure facilitated by sacrificing the lower portion of the sacrum. In such an instance the fossa should be drained and *a temporary colostomy should be established.*

4. Retroperitoneal pelvic space: This potential space is chiefly involved by perforation of the rectum, and the general surgical principles to be followed are the same as for penetration of the peritoneal cavity.

5. Pelvis or peritoneal cavity: When there is evidence of perforation of the rectum or colon manifested by signs of irritation of the peritoneum, namely, abdominal distention, generalized or lower abdominal tenderness and absence of peristalsis, either with or without external perineal or anal injury, surgical exploration of the abdomen should be undertaken.

Surgical exploration is adequately accomplished through a low left rectus incision, remembering that the patient should be placed on the operating table in the Trendelenburg position. The entire small bowel should be inspected from the ligament of Treitz to the ileocecal junction after which the entire colon should be examined. To facilitate examination of the colon the small bowel can be removed from the pelvis and packed away from the pelvic region by the use of large, moist laparotomy pads. Adequate examination of the descending and sigmoid colon, the bladder and the peritoneal reflection in the pouch of Douglas must be made. Intraperitoneal damage will be obvious; however, retroperitoneal injury to the bowel, bladder or mesentery of the colon may require careful search. Extraperitoneal hemorrhage suggests exploration of the retroperitoneal structures. This should be done by incising the lateral and mesial reflections of the parietal peritoneum, along the edge of the colon distal to the sigmoidal branch of the inferior mesenteric artery, and uniting these incisions in the pelvis anterior to the rectosigmoid junction. This maneuver mobilizes the colon and permits the rectosigmoid colon to be retracted superiorly. Perforation of the bowel or bladder below the pelvic diaphragm can be seen and proper closure of these rents accomplished.

When there is injury to the bladder wall, subrapubic cystostomy is indicated. With perforation of the rectum or colon a loop colostomy proximal to the perforation is the procedure of choice. A precolostomy, using a glass rod between abdominal wall skin and the colon, can

be performed and temporary colostomy made only if indicated. It is not necessary to close the opened pelvic peritoneum, but drainage of the retroperitoneal space, either extraperitoneal or transperitoneal in position, is an added factor of safety.

Postoperative Treatment. Following surgical explorations supportive treatment consists of continuous gastric suction until the signs of peritoneal irritation have disappeared. Water and electrolyte balance must be maintained. Whole blood should be administered until the blood loss is corrected. Chemotherapy should be continued. If peritoneal cultures reveal organisms susceptible to specific chemotherapeutic agents based on sensitivity tests, these agents should be given as soon as possible. Day by day observations indicate the need for colostomy if precolostomy has been done. General and local complications must be constantly sought for and corrected without delay.

The following specific case reports will serve to emphasize these surgical principles:

CASE REPORTS

CASE 1. W. M., a twelve year old white male, was admitted to the Children's Hospital October 15, 1949.

Eight hours before admission, while working on his father's farm, he sat down on a bundle of corn and a corn stalk penetrated his trousers going into his anus. Immediately he became ill with lower abdominal pain and vomited four times. His father consulted a local physician who noted abdominal rigidity and tenderness with absence of peristalsis. He was brought by automobile to the hospital, a distance of 75 miles.

On admission physical examination revealed the boy's temperature to be 101°F, pulse 120, respirations 36 and blood pressure 110 systolic over 40 diastolic. His skin was dry and he appeared to be in acute abdominal distress. There was no evidence of peripheral vascular collapse. The pertinent findings were limited to the abdomen and perineum. The abdomen was slightly distended associated with generalized rigidity most marked in the lower quadrants. There was generalized tenderness and no peristaltic sounds could be heard. In the anal region an abrasive wound could be seen near the anterior edge. Digital rectal examination revealed perforation of the rectal wall 6 cm. from the anus, and the rent would admit the finger tip.

Laboratory data revealed a red blood count of 5.2 million, hemoglobin 13.2 gm. and a white blood count of 38,000, with 96 per cent polymorphonuclear leukocytes. Urinalysis revealed 1 plus albumen, a few white cells and many red cells.

The patient was observed for a period during which penicillin (400,000 units), streptomycin (500 mg.) and tetanus antitoxin were administered.

Exploration was done approximately ten hours after injury through a left rectus incision. The abdominal cavity contained excessive clear, yellow fluid and pieces of corn stalk. The small bowel was explored and there was no evidence of injury. With the patient in the Trendelenburg position the large bowel was explored and the pelvis was walled off from the remaining peritoneal cavity by means of laparotomy sponges.

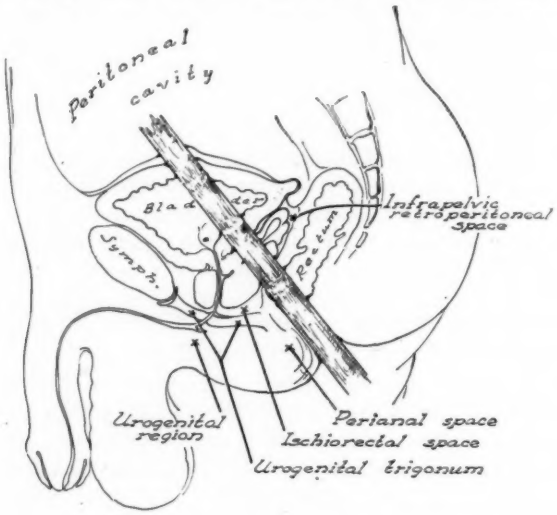
A 1-cm. perforating wound in the dome of the bladder was seen. This wound was enlarged with a transverse incision permitting excellent vision of the interior of the bladder. The inferior perforation could be seen in the middle trigone region slightly superiorly and in the midline between the ureteral orifices. Without other peritoneal perforations it was obvious that the cornstalk had gone into the anus, perforated the rectum, passed into the infrapelvic retroperitoneal space and penetrated the bladder inferiorly and superiorly. (Fig. 3A.) The lateral and mesial peritoneal leaves of the sigmoid colon were incised and joined in the pouch of Douglas. The rectosigmoid colon was mobilized and the perforation of the anterior rectal wall was easily seen and closed with two rows of No. 000 chromic catgut using a Connell suture. The inferoposterior rent in the bladder was closed with interrupted sutures of No. 000 chromic catgut using an intramural row and a second reinforcing suture. The bladder mucosa of this rent was approximated with inverted sutures of No. 0000 chromic catgut. A suprapubic cystostomy tube was placed in the bladder and the cystotomy wound was closed as the inferior rent had been, with three rows of catgut. (Fig. 3B.) Two drains were placed in the space of Retzius and three drains were placed to the retroperitoneal pelvic space. No attempt was made to close the pelvic peritoneum. The drains were brought out through the lower angle of the rectus incision. A precolostomy was developed holding the sigmoid colon over a glass rod. The left rectus incision was closed with through and through silver wire, approximating the peritoneum and rectus sheath with catgut.

Postoperatively, fluid and electrolyte balance was maintained. Whole blood was given, chemotherapy continued and gastric suction instituted. Within forty-eight hours peritoneal irritation became less marked and liquid feeding was started. There was no indication for opening the precolostomy. The patient's course was good and by the seventh postoperative day he was afebrile. On the ninth postoperative day the exteriorized loop of colon was replaced to the peritoneal cavity. Laboratory tests indicated normal kidney function. The patient's wounds healed without infection and he

was discharged on the twenty-second hospital day.

Follow-up examinations have been entirely satisfactory and the patient has recovered without any complications or sequallae.

Comment. This case demonstrates extensive injury to the rectum and bladder involving the infrapelvic retroperitoneal space. The principles of surgical care have been emphasized. Further, this case demonstrates a direct method of trauma to the anal region, the rectum, the infrapelvic space and the peritoneal cavity. In the production of this serious injury the bladder was involved and, fortunately for the patient, the ureteral orifices and the ureters were spared injury. Unquestionably, chemotherapy has aided a great deal in lessening morbidity in this type of injury. It must be remembered, however, that sound surgical principles must be followed in order to obviate serious complications.



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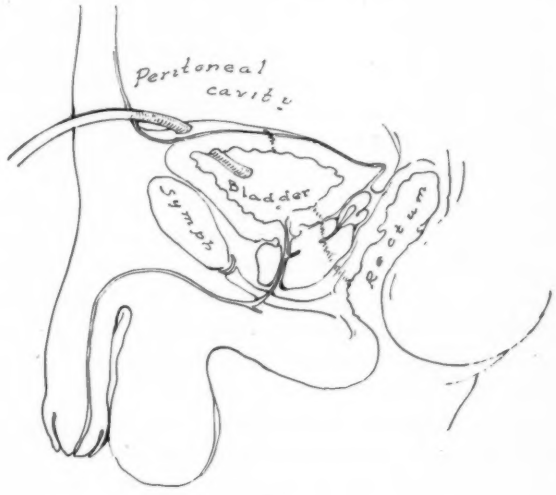

3B

FIG. 3. A, sagittal view demonstrating the pathway of the corn stalk producing perforation of rectum and bladder before entering the peritoneal cavity; B, sagittal view showing reconstruction of rectal and bladder perforations.

CASE II. N. S., a fifty-nine year old white female, was admitted to the Christian R. Holmes Hospital on June 2, 1949, with a diagnosis of Korsakoff's syndrome, obesity and chronic phlebitis of both lower extremities. Three weeks after admission to the hospital the nurses noted fecal material passing from the vaginal orifice. Previous rectal and vaginal examinations had been negative. Examination at this time revealed small fibrous anal skin tags and a rectovaginal fistula above the internal sphincter. A proctoscopic examination was made and the exact location of the fistula was noted. The fibrous anal skin tags were numerous and because of their appearance biopsies were done. Cytologic study of the tissue revealed fibrosis and chronic inflammation. A sigmoidoscopic examination was made and the entire lower gastrointestinal tract was found to be otherwise normal. The patient had been given daily enemas and it was assumed that the rectovaginal septum had been perforated inadvertently.

On July 13, 1949, an attempt was made to close the rectovaginal fistula by means of a modified posterior colporrhaphy procedure. The rectal mucosa was approximated with interrupted catgut sutures and the vaginal portion of the septum was closed in a similar fashion. Every attempt was made to perform a very careful procedure; yet, with the lower gastrointestinal tract functioning, this repair was inadequate, infection followed and the fistula persisted.

On August 16, 1949, a loop colostomy was developed and the fecal stream diverted. On August 26, 1949, a first stage fistulectomy was accomplished and a seton was placed in the fistula and around the sphincter muscles. No further surgery was done until March 4, 1950, when a second stage fistulectomy was successfully accomplished, removing the seton and dividing both of the sphincters after fibrosis had developed around them. This completely obviated the rectovaginal fistula and the anal wound healed without difficulty. The severed ends of the anal sphincter muscles reunited to give a very good anal orifice. On May 11, 1950, the colostomy was repaired by complete resection of the loop and an aseptic end-to-end anastomosis was accomplished.

This patient made an uneventful recovery from the rectovaginal fistula; however, it is to be noted that several operative procedures were necessary to accomplish this purpose.

Comment. This case exemplifies one of the common types of direct trauma in which the rectovaginal septum may be perforated. As has been pointed out in the literature, many patients receiving enemas have had similar perforations on this part of their gastrointestinal tract. The extent of surgery required to correct such a small fistula demonstrates clearly the seriousness of this type of injury.

SUMMARY

The problems which arise from wounds of violence to the perineum, anus, rectum and colon have been discussed in terms of anatomic structure. There are two types of violence to this region, namely, direct and indirect. A review of the regional anatomy denotes five cardinal sites of involvement from deep penetrating wounds, namely the urogenital region, the anal region, the ischiorectal fossa, the retroperitoneal infrapelvic space and the pelvis or peritoneal cavity. In the early postaccident period the ischiorectal fossa and the infrapelvic retroperitoneal space are clinically silent regions. Serious complications and death from infection may be prevented if all patients are thoroughly studied by proctosigmoidoscopy and properly treated. In consideration of the bizarre types of injuries preoperative, operative and postoperative surgical treatment have been presented. The case reports clearly emphasize most of the surgical principles involved.

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DISCUSSION OF PAPERS BY DRS. CRIKELAIR AND BATES, VENABLE AND PULASKI, AND SILER

Arthur R. Metz (Chicago, Ill.): I wish to compliment Dr. Siler on his discussion of injuries to the lower abdomen and pelvis. I wish, also to call attention to the problem of ruptured urethra when it is severed making it impossible to pass a catheter.

A method has been described by Dr. George G. Davis of Anchorage, Alaska, in which he has recommended doing a suprapubic cystotomy; then with two especially designed urethra sounds, one of which has a blunt tip on the end and the other a socket, he passes the pointed sound into the urethra to the point of the rupture and then passes the other sound with the socket into the urethra from the bladder side until they meet. By getting the two sounds end by end he is able to pass the urethra sound on into the bladder. He is able, then, to attach a catheter to the urethra sound, in which there has been a hole bored, by means of a suture and bring the catheter out through the urethra which acts as a splint. The urethral mucosa tends to regenerate rather promptly and heals along the catheter so that the urethra is reconstructed. A suprapubic drain is inserted into the bladder to allow for drainage. The catheter in the urethra is sutured and taped to the meatus and is kept clamped for about seven days when it is opened and allowed to function. As a rule it can be removed within twelve to fifteen days.

This method eliminates the necessity of excessive perineal dissection where it is often very difficult to find the opposing ends of the urethra. This was described many years ago by Dr. Davis but has perhaps been overlooked by many surgeons who are doing surgery of trauma at this time.

Donald M. Glover (Cleveland, O.): I should like to commend, first, the very able presentation on the treatment of osteomyelitis by Dr. Venable and Colonel Pulaski who combined admirably bacterial control with reconstruction of the destructive process.

I might call attention to the fact, however, that the type of sliding flap which was described in the lower leg is not always adequate for covering the surface where the defect in the tibia is quite large, and it may be necessary to use a pedicle flap of larger size from a more remote area, preferably the abdominal wall, carried down via the wrist. When it is necessary to delay the flap, it may be quite useful to line the bone cavity with split-thickness skin immediately. This cuts down the problem of bacterial control in the cavity during the interim.

I should like also to comment upon the very interesting presentation of Drs. Crikelair and Bates on the rather unusual problem of human bite of the face. I should like to commend the presentation that was given and the very nice, well organized illustrations which Dr. Crikelair used. I think he has emphasized a principle which is worth while in conserving tissue of the face.

It has become pretty generally agreed, I think, that extensive débridement of the face should be avoided in any type of injury since it is almost impossible to replace lost soft tissue of the face adequately. The author's presentation would make us feel safer in the retention of damaged tissue of the face, even in the instance of human bites, in which at least theoretically the type of bacterial contamination may be a serious one. If his contention is correct, and I believe it is from my own experience, conservative type of treatment of these injuries with conservative débridement and primary closure where infection is not already present certainly seems indicated and will certainly save the patient a good deal of trouble and time.

R. Arnold Griswold (Louisville, Ky.): Colonel Pulaski and Dr. Venable have illustrated one of the greatest advances that have been made in surgery in the last few years. We can all remember the day when osteomyelitis of any type was a recurrent, lifelong disease. I recall a patient who had had seventeen operations on a femur in a period of twenty-five years following a compound fracture in World War I. This has now remained closed and asymptomatic for several years as a result of a similar type of treatment.

One thing which particularly impressed me was the fine bacteriologic control illustrated. A good many of us have thought that with the advent of penicillin and sulfonamides surgical bacteriology was an obsolete science. This is certainly not true although it is not usually carried out as meticulously and thoroughly as they have been able to at Brooke General Hospital.

It is difficult in many hospitals to get good bacteriologic control. This is probably not so much the fault of the bacteriologist or the laboratory people as it is our own fault, for not demanding the type of bacteriologic control which has made this work possible.

GROVER C. PENBERTHY (Detroit, Mich.): The approach made by Colonel Pulaski and Dr. Venable in the management and treatment of this surgical lesion, chronic osteomyelitis, is constructive and a great contribution. The authors have emphasized sound surgical principles and have shown, as Dr. Griswold has said, the value of bacteriologic studies.

The importance of maintaining the nutrition of the individual as well as improving the peripheral circulation has also been emphasized, as Dr. Pulaski referred to it, by sympathetic block and even sympathectomy to improve the peripheral circulation. That, no doubt, is of great importance as are the blood volume studies.

I think as Dr. Venable has presented this one case, the lower end of the tibia is striking, emphasizing what can be accomplished in the application of sound surgical principles and careful follow-up.

Furthermore, as Dr. Griswold has said, the idea in the general hospital would be to carry through with this program. However, I asked Colonel Pulaski if he thought it would be practical in the general hospital today where personnel is short, or slim at least, and the interest not always present. I think, as Dr. Griswold said, we as surgeons should demand and at least request that such follow up studies be made, important as they are, because the cases of chronic osteomyelitis will run for years. Many of us have seen such cases. With this approach as the authors have given it to us it is sound and constructive.

I also wish to compliment and commend Dr. Crikelair, as a collaborator with Dr. Bates, for his presentation. I had the good fortune to see some of these cases, and the interest which the young men who handle these cases are showing is very encouraging.

With regard to Dr. Siler's presentation, that, too, is an excellent piece of work and demonstrates the thoroughness of approach that must be made with the individual who has a perineal injury as he described. I congratulate him.

CHARLES HUGH MAGUIRE (Louisville, Ky.): I wish to compliment and commend Dr. Siler for his presentation and for adding cornstalks to the list of implements as that is one of the major offenders in our neck of the woods.

One factor should be emphasized in regard to the physical make-up of the perineal area. In this region because of the anatomy there is actually a truncated cone which will guide most rounded objects directly toward the anus. A broom handle, hoe handle or pitchfork handle if directed toward the general perianal region may bounce off the ischial tuberosity or off the skin and when hitting the sphincter will penetrate; hence, the physical presence of a cone which will guide an object to the sphincter is an important factor and one that has been overlooked a good part of the time.

With regard to therapy, I wonder whether a colostomy is always necessary in rectal or perirectal and sigmoidal injuries. Adequate preparation before surgery and delicate dissection of devitalized tissues with careful adequate closure of the perforation may make colostomy unnecessary. Low-lying perforations of the rectum and rectosigmoid may be put into an extraperitoneal position with mobilization of the peritoneal reflection and reattachment of the peritoneum at a higher level. At the time of surgery dissection may be carried down into the retrorectal space and into the hollow of the sacrum. Then, after closure of the abdomen, an elliptical incision can be placed posterior to the sphincter and dissection carried upward into the hollow of the sacrum, joining the space formed from above. Drains may then be placed into this area which will give adequate protection. With these things in mind I wonder whether colostomy and any elaborate method of drainage are necessary.

I enjoyed the papers very much, and I think that Dr. Siler certainly brought up a subject which is too frequently mishandled.

CALEB H. SMITH (Bradford, Pa.): I enjoyed Dr. Siler's paper and I would like to emphasize a point or two which he made with regard to wounds of the rectum.

The anatomy of the pararectal space plays an important part in infection that follows wounds of the rectum. The rectum is surrounded by a layer of fat which in turn is confined by a layer of fascia. Infection of the fatty layer following a wound of the rectum thus results in a closed-space type of infection and the patient becomes toxic rapidly. Furthermore, the pararectal fat is continuous with the preperitoneal fat to which infection quickly spreads. Here, too, the infection is confined by the transversalis fascia, which is continuous with the pararectal fascia, and perinephritic abscesses and even perforation of the ascending colon have resulted from the spread of infection following a wound of the rectum.

These circumstances make it obvious that drainage, early and adequate, of the pararectal fatty layer is an essential factor in the treatment of wounds of the rectum. During the first World War the mortality for wounds of the rectum was approximately 40 per cent, whereas in the last war it was below 10 per cent. Admittedly, many factors entered into this reduced mortality, but the proper use of drainage was one of the greatest factors. In the treatment of wounds of the rectum drainage of the pararectal fat is so important and so simple to establish—it can be accomplished with an incision at the tip of the coccyx or a para-

coccygeal one—that it should be carried out when a wound of the rectum is suspected.

As Dr. Siler stated, wounds of the rectum must be repaired meticulously. If they are not carefully repaired, they will reopen when the colostomy is closed thus leaving the patient in the unfortunate predicament of requiring a second colostomy and repair of the wound of the rectum.

I am inclined to agree with Dr. Maguire that when a wound of the rectum is immediately repaired with care and adequate drainage of the area established, colostomy may be avoided. The fact that colostomy in the treatment of wounds of the rectum is a generally accepted measure today bears testimony to the seriousness of the infection that follows such wounds. Although colostomy may be avoided, the surgeon who establishes one cannot be criticised.

CHARLES S. VENABLE (closing): First, I want to say, regarding the remarks made by Dr. Glover about lesions of the tibia, they are very, very true, particularly when the lesions are badly mixed up in the skin; in many of those instances we use cross-leg full-thickness grafts. Not very long ago I counted as many as seven cases with cross-leg full-thickness grafts in order to get sufficient skin. I do not think I have had experience with using skin from the abdomen on down to the lower leg. It is a little better, I think, with the cross-leg.

I want to say that we give all credit to Colonel Pulaski who has done a marvelous job and follow-up of research in the work which he has done at Brooke.

VINTON S. SILER (closing): I had hoped that my paper on precolostomy and colostomy in the management of perforations of the rectum and colon would provoke discussion. Time does not permit me to debate this issue; nonetheless, I believe that Dr. Maguire and Dr. Smith answered many questions in your mind.

In some instances the surgeon may obtain an adequate repair of the rectal perforation and believe that colostomy need not be done. In other cases he may not feel as secure about the repair and may unhesitatingly perform a colostomy. Little doubt remains about the factor of safety with precolostomy and colostomy. On occasions some of us have experienced unnecessary complications after leakage of a repaired perforation of the bowel in spite of a closure deemed more than adequate at the time of operation.

With a well trained surgical staff observing details in the postoperative patient closely, one might delete some of the rules of safety; however, the majority of surgeons operate under less well controlled circumstances. In any event there is less risk to life when sound surgical principles are followed. We believe that precolostomy and colostomy are sound principles in the management of perforations of the rectum and colon as stated in our presentation.

YOUR HIPS AND MINE

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"SHE has a bad heart. It would not be safe to operate on her broken hip." "She is too old and feeble to take an anesthetic." In other words, internal fixation of a fractured hip must be reserved for patients under fifty and for the unusual older person in robust health. The reader may smile, but in the smaller communities and away from the Medical Centers this is a common belief. Operations on fractures of the upper extremity of the femur are radical procedures to be entered upon only after adequate study of the patient who during the week to ten days necessary for this study must lie in bed with sand bag immobilization.

The purpose of this paper is twofold: First, the writer will attempt to disprove the foregoing statements by presenting a series of unselected consecutive cases; second, the widespread education of the general practitioner and internist is urged in the principles underlying the internal fixation of broken hips. In most communities other than the largest cities the general practitioner sees these patients first. It is he who refers them to the hospital or watches them at home for a few days and it is he who advises the family as to the best treatment. He is not interested in whether the specialist uses ten penny nails or a silver screw in the operation, and he is only academically interested in the problem of aseptic necrosis. What he wants to know is what method of treatment will give the elderly patient the best chance of getting back to her family with the least pain and discomfort to her and with the least financial distress to her family. He also wants to know if the small local hospital is equipped to handle cases of this type or if the patient must be transferred to the nearest medical center.

In an attempt to answer the problem the following analysis of forty-two consecutive cases of fractures of the upper extremity of the femur is submitted. No differentiation has been made between intracapsular and intertrochanteric fractures for the questions of operative technic and of late results do not come within the scope of this paper. All of the forty-two patients were treated in the last two years by the same surgeon in a 100-bed hospital and most of them were seen by one physician.

The age distribution is the usual one in this type of fracture. Thirty of the forty-two patients were seventy years of age or older, seventeen were over eighty years of age and one was ninety-one.

Thirty-two patients were admitted to the hospital less than twenty-four hours after injury, but at first neither the hospital nor the community considered a broken hip as an emergency and the surgeon frequently was not called to see the patient until several days had elapsed. This attitude gradually changed, however, and it is now a rare case that is not seen by the surgeon within an hour of admission.

Thirty-five of the forty-two patients were operated on, twenty-one in less than seventy-two hours after admission to the hospital and another four within twenty-four hours after being seen by the surgeon. This needs to be emphasized as illustrating the value of education. During the first six months of this study the majority of patients were operated on after forty-eight hours following admission to the hospital. During the last six months all patients were operated upon within the first forty-eight hours.

In order to satisfy the general practitioner and to get the best possible care for the patient almost every case was evaluated medically by an internist who became much interested in the problem and completely persuaded as to the value of internal fixation. At first he examined the patient to see if it would be safe to operate. Now he examines them to see if it would be safe to delay operation.

The preoperative medical evaluation revealed twenty-seven patients with compensated arteriosclerotic heart disease and eight patients in cardiac failure at the time of admission. Only four patients of the series

showed no heart disease. There were thirty-seven other medical complications including diabetic coma, cerebral accident, diaphragmatic hernia and bleeding peptic ulcer. One patient had six complications. There were eight postoperative complications including four bed sores, one senile dementia, one pneumonitis, one gastrointestinal bleeding and one urinary infection.

There were no deaths within thirty days of operation in the thirty-five patients who were treated with internal fixation of their fractures. On the contrary, it is interesting to note the universal improvement in the condition of the patients after the fixation of the fracture. One woman of eighty-four who was in cardiac failure when admitted and who had a pulse rate of 120 was operated upon within forty-eight hours. She was out of bed the following day; two days postoperatively her pulse rate was 70. An eighty-two year old woman was admitted with the preoperative findings of nodular goiter, arteriosclerotic heart disease, an enlarged liver and carcinoma of undetermined origin. She was operated upon within seventeen hours of injury and was out of bed the next day. An eighty-seven year old woman was admitted in marked cardiac failure. She was operated upon twenty-one hours after injury. She was out of bed the following day and progressed most satisfactorily under a medical regimen for her cardiac condition. One seventy-six year old woman with an intertrochanteric fracture was treated in another hospital with skin traction. She became wildly disoriented and after four days was transferred to the State Hospital. In the transfer her traction was removed and she quieted down to such an extent that after a brief sojourn at the State Hospital she was sent home. Her family was unable to cope with the situation as the fracture was still unreduced and unprotected so the patient was admitted to another hospital three weeks after injury still completely disoriented. She was operated upon three days after admission and was out of bed the following day. In nine days her sensorium had cleared completely and she was able to go home to her family who could then manage her care with ease.

There were two deaths in our series, one forty-two days after operation and one fifty-seven days after operation. These deserve special mention. The first was in the case of a sixty-eight year old man who was admitted two hours after injury. On admission he was disoriented and confused. His medical diagnosis included barbiturate and narcotic addiction, arteriosclerotic heart disease with chronic failure, bronchiectasis, convulsive disorder and chronic cystitis. He had only one kidney and had had multiple abdominal operations for ulcer. As soon as the physician had examined the patient, he phoned the surgeon to urge immediate operation because he was afraid the patient would not live twenty-four hours. Operation was performed five hours after injury; and although the immediate postoperative course was complicated by severe convulsions, the patient was out of bed in five days, rational and alert. He continued to improve but, unfortunately, on the thirty-seventh postoperative day developed an uncontrollable kidney infection and died on the forty-second day of uremia and terminal bronchopneumonia which made its appearance forty-eight hours before death.

The other death was in the case of a sixty-four year old woman who had a chronic urinary infection on admission. She was operated upon the fourth day after admission. She progressed fairly well and was able to leave the hospital on the twentieth postoperative day. However, she died of uremia in a nursing home fifty-seven days after operation.

The procedure that has been observed in these cases is as follows: The physician is called as soon as the surgeon has seen the patient and institutes what treatment he considers necessary (digitalis, insulin). If the patient is seriously ill or has been injured within twenty-four hours of admission, operation is performed at once. Operation is delayed only in those cases in which the physician considers the patient to be in good health. The anesthesia used on all these cases has been pentothal® induction followed with nitrous oxide and oxygen and has been most satisfactory. Twenty-six of the thirty-five patients were out of bed the day following operation and six more were allowed out of bed after forty-eight hours. There were no wound infections.

Of the seven patients who were not operated upon, one refused surgery; one patient had muscular dystrophy with cord degeneration and was bedridden before her fracture; one patient had a refracture, an undisplaced crack,

three weeks after internal fixation had been applied elsewhere; one was a blind, deaf, senile and incontinent patient who had been bedridden for five years; two were admitted with severe bronchopneumonia and had grossly comminuted intertrochanteric fractures (these patients were out of bed in Wilkie boots the day after admission); and one was moribund on admission and died of uremia in a couple of days.

It is indicative of the change in point of view among our colleagues that now very good reasons for not operating on a patient with a broken hip have to be advanced before they are satisfied. Internal fixation is frequently urged in spite of technical difficulties obvious to the surgeon. This could not have come about but for the active and intelligent cooperation of the internist and the anesthetist whose unfailing interest and understanding have made these results possible.

The principles involved are simple enough. By fixing the broken bone ends pain is minimized and shock greatly reduced. The patient can be moved with relative ease, which is a most important consideration in these elderly people. The broken hip thus becomes an incidental factor in the treatment of the patient and attention can be directed entirely to the medical problems of the individual.

In conclusion, a series of forty-two cases of fracture of the upper extremity of the femur have been analyzed in an attempt to show that age and illness not only are no contradiction to internal fixation but also frequently make it the treatment of choice.

MEDULLARY FIXATION OF FEMORAL SHAFT FRACTURES*

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BÖHLER makes the following statement in the preface to his recent book on medullary nailing: "Küntscher's medullary nailing is an astonishing and important innovation in traumatic surgery. Compared with our previous experiences, it is amazing to see a man with so serious an injury as a femoral fracture, walk painlessly two weeks later with neither cast nor brace and with freely movable joints."

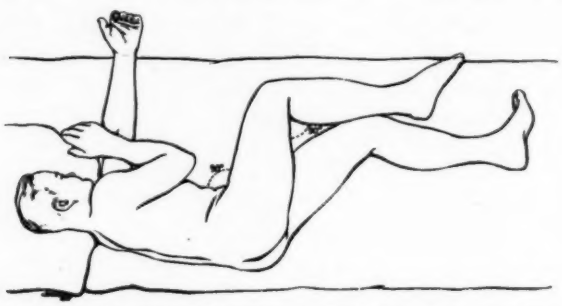

FIG. 1. Illustrates the proper position of the patient on the operating table.

Medullary fixation is not new, but general interest in the procedure has been aroused in this country only during the last few years. There are many surgeons who will doubtlessly not agree that it is an important innovation in traumatic surgery. There are many questions to be answered; therefore, it is hoped that other large series of cases will be published so that we may all profit from the experiences of each other. I wish to quote from the Report of the Committee on Fractures and Traumatic Surgery of the American Academy of Orthopedic Surgeons: "Within the year it is hoped that the equipment will be perfected, and that the technique will be standardized to the point where intramedullary fixation can be generally accepted as a reliable and satisfactory, though not fool-proof, form of therapy for the femur."

TECHNIC

Closed reduction under fluoroscopic control as practiced by the European surgeons has not been attempted by us. In the open method the fracture is reduced under direct visualization and the nail may be inserted either through the trochanter or retrograde into the proximal fragment. In our first eight cases we inserted the nail into the trochanter. However, we found this method to be fraught with both danger and difficulty. Since then we have used a retrograde technic exclusively. The technic is carried out as follows:

Prior to operation the length and width of the nail to be used is determined. This is done by flexing the hip and knee of the well leg to 90 degrees and measuring from the tip of the trochanter to the knee. If the fracture is low, nothing is subtracted from this measurement. If it is at the isthmus or higher, 1 inch is subtracted from the measured length. Diamond nails are supplied in widths of 9 mm. and 11 mm. These will be found adequate for almost all adult femurs. Böhler advocates subtracting 2 mm. from the x-ray width of the medullary cavity to determine the proper diameter of the nail.

At operation the patient is placed on his unaffected side with the involved extremity flexed 90 degrees at the hip and knee. (Fig. 1.) A posterolateral incision is made exposing the fracture site. The incision need only be long enough to allow the bone ends to be grasped with the bone-holding forceps. A ¼-inch drill bit is then drilled up the proximal fragment and out the trochanter until it points beneath the skin. A stab wound is then made over its point. The drill bit is withdrawn and the nail driven out the trochanter until the tip just disappears in the proximal fragment. The fracture is reduced and the nail driven home. In a fresh transverse fracture this operation should require no more than thirty minutes to accomplish.

Indications. The indications for this technic are as follows: (1) all fractures of the shaft of the femur if they are at least 2½ inches removed from the tip of the trochanter or the knee joint; (2) severely comminuted fractures

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2A 2B 2C

FIG. 2. A, diamond nail inserted to proper length; B, bending of the nail due to trauma three months postoperatively; C, straightening of nail following manipulation under general anesthesia.

require additional fixation; (3) non-union and delayed unions are especially suitable to this method; (4) medullary fixation is indicated in many pathologic fractures; (5) the medullary nail is useful in leg-shortening procedures; (6) compound fractures may be so treated when the danger of infection is passed; and (7) intramedullary fixation may be employed following osteotomy of the femur to correct certain deformities.

Results. In this series of seventy-four cases we have used three types of nail, namely, the V-shaped nail of Küntscher (eight cases), a U-shaped nail (five cases) and the diamond-shaped nail in the remainder (sixty-one cases). We have discarded entirely the V-shaped nail, as in every case in which it was used the nail either bent or fractured. One of our staff still prefers the U-shaped nail but the remainder believe the diamond shape to be the most satisfactory. In only one case has the diamond-shaped nail bent. This was in an eighteen year old boy who was knocked from his bicycle by a car when the fracture was three months old. (Fig. 2). The nail was straightened by manipulation under anesthesia without difficulty. The complications in this series have been few and, except for the aforementioned, none has been serious. There have been no infections, no clinical manifestations of fat embolism and no non-unions. Two nails have migrated outward but each was driven back under local anesthesia. Painful bursitis developed over the nail in one instance. This was due to the fact that the nail protruded too far beyond the trochanter.

Medullary fixation has been carried out in three pathologic fractures with very gratifying results.

I believe that medullary fixation does somewhat delay callus formation and bony union but it is of little consequence as the patients are ambulatory and often return to heavy work in three to four weeks. The earliest a nail has been removed in this series is four months, the latest sixteen months. Thus far the average has been thirty-eight weeks. This average has doubtlessly been increased by the reluctance of

several patients to enter the hospital for the removal.

SUMMARY AND CONCLUSION

Seventy-four cases of fracture of the femur treated with medullary fixation have been presented, with results and complications. The diamond-shaped nail is believed to be the nail of choice and we have considered the results excellent in all cases in which it was used.

This procedure is not a foolproof one. Surgical skill and judgment are the first prerequisites to its use.

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INTERNAL FIXATION WITH SMITH-PETERSEN NAIL AND EXTENSION BAR IN TREATMENT OF INTERTROCHANTERIC FRACTURES OF FEMUR

REVIEW OF 132 CASES

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IN presenting the results of intertrochanteric, pertrochanter and subtrochanteric fractures of the femur treated with internal fixation using the Smith-Petersen nail and an extension bar we should like to report favorably upon a method which to some may seem radical. Several questions may be raised as to whether internal fixation should be recommended as the optimum method of treatment. In our opinion it should. Although we realize that union may be obtained with traction methods, either Russell traction or skeletal traction, we believe definitely that prolonged bed rest, particularly in the older age group in which this fracture so frequently occurs, should be avoided if possible. The complications incident to prolonged traction in the aged are well known. Pressure sores, hypostatic pneumonia, thrombophlebitis, loss of weight and strength, psychoses, stiff knees and hips, and a long period of rehabilitation are some of the complications and sequelae that are frequently seen. It is a common fallacy that good results in this particular fracture will always ensue regardless of the mode of treatment. What is lost sight of, however, is that when a traction method is used, the ultimate mortality rate, due to prolonged bed rest with its accompanying complications, is much higher than is frequently thought. This fracture usually occurs in the advanced age group and is very seldom seen in individuals under sixty years of age. The average age in our series was seventy-three years. It is well known that at this time of life bed rest for any length of time is not desirable. In going over our mortality figures from 1930 to 1940, considering only those cases in which patients were treated with Russell traction, we were surprised to find that we had a hospital mortality rate of 24 per cent. In contrast to the traction methods internal fixation permits the patient to be ambulatory very soon after the operative fixation and most of the aforementioned complications are avoided. The aged stand the operation very well, as has been seen in nailing intracapsular fractures of the femur, and it is our belief that if they do not survive the operative treatment many of them would not have survived very long without it. Most patients in their seventy's or eighty's have good vital organs; otherwise they would not have lived to such an advanced age. As the average span of life increases, the problems of geriatrics come increasingly to the fore. Those of us who have had the opportunity of operating upon these elderly people for any variety of surgical conditions have become more and more aware of their ability to withstand surgical procedures of the utmost gravity. Colon resections and gastric resections for carcinoma may be cited as examples, and with adequate preparation, supportive blood transfusions and modern anesthesia we are completely convinced that the surgeon in most instances is on safe ground.

We started treating intertrochanteric fractures with internal fixation in 1937. Our cases at first were very carefully selected; but as we began to note our improved results, we soon made it the routine procedure for this fracture. Since 1940 all of these fractures have been treated with this method. The Moore-Blount angle iron was used in the first twenty cases but we soon found we were having difficulty in the insertion of this into the upper fragment. The hold in the upper fragment in some instances was not adequate and loosening occurred. We shortly gave it up in favor of the Smith-Petersen nail with an extension bar. At first we used the Smith-Petersen nail with a Thornton extension bar but now we

FIG. 1. Case 1. Intertrochanteric fracture in a woman of seventy-three; after reduction with Russell traction. (Note towel clip too high.)

use the Smith-Petersen nail with a McLaughlin bar. The Jewett nail may be used if preferred but either is a matter of individual choice. Some of those using the Jewett nail do so because they believe the nail and extension bar being in one piece is more stable at the junction between the nail and extension bar than when the nail and bar are used separately as in the Thornton or McLaughlin bars. This, however, has not been our experience. We have not had a single nail or bar break or bend in this series since we discarded the Moore-Blount angle iron and believe that if the extension bar is screwed tightly into the base of the nail breakage at this point is most unlikely. We do advise that if the Thornton bar is used the lock washer should be omitted. We had several instances early in our experience in which the bar and nail came apart several weeks after operation due, we believed, to too much space having been taken up by the washer. Since omitting the use of the washer we have had no instance of subsequent separation. (Figs. 1 to 12.)

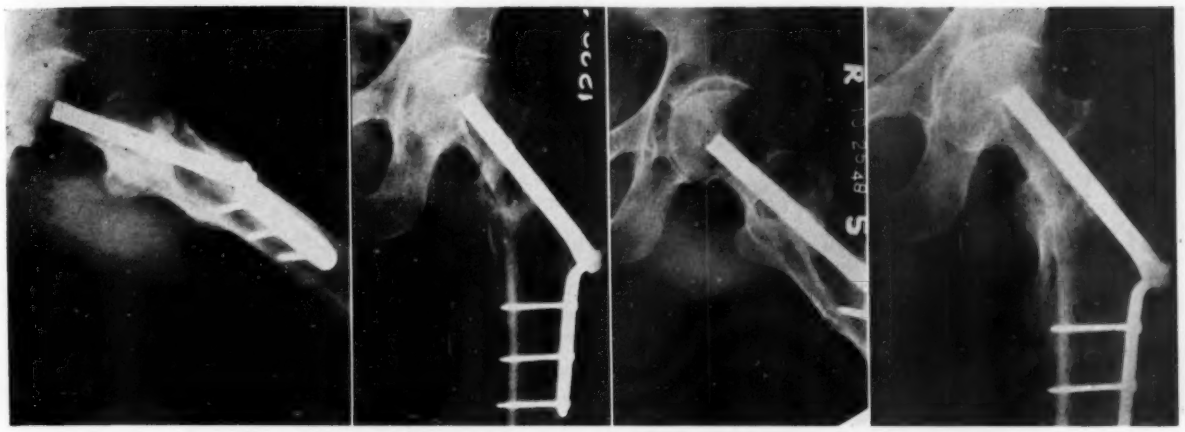
Our routine for handling these patients and the operative technic may be summarized as follows:

Upon admission to the hospital the extremity is placed in Russell traction with a 10-pound weight. During the ensuing five to seven days before operation the patient's general physical status is evaluated. Electrocardiogram, blood chemistry, x-ray of chest, urinalysis, complete blood count, blood typing and a careful physical examination are done. We do not believe that nailing this fracture as an emergency procedure is indicated. Any cardiac or renal disease is treated, the diabetic is brought under control and the patient's fluid balance, if necessary, is restored. During this period the patient generally gets over the shock of the injury and becomes a much improved operative risk. In addition the Russell traction practically always reduces the fracture so that manipulative reduction in the operating room is rarely necessary. This, we believe, is most important. Many of these fractures are comminuted. Manipulation tends to increase this comminution and in addition to increase shock. If manipulative reduction does prove necessary, it should always be done gently and with great care.

Two days before operation careful skin preparation of the thigh, abdomen and back is done. This consists of shaving, scrubbing for five minutes with soap and water, the application of 3½ per cent tincture of iodine, washing with alcohol and encasement in sterile drapes. This skin preparation, except for shaving, is repeated twenty-four hours later. The sterile drapes are then left on until they are removed in the operating room. It is our belief that this forty-eight-hour skin preparation helps decidedly in reducing the chances of infection and we use it routinely in all bone operations. It may be that one of the G-11 preparations such as phisoderm will replace this routine as a quicker and more efficient bacteriocidal method of skin sterilization. So far, however, we have not used G-11 for this purpose.

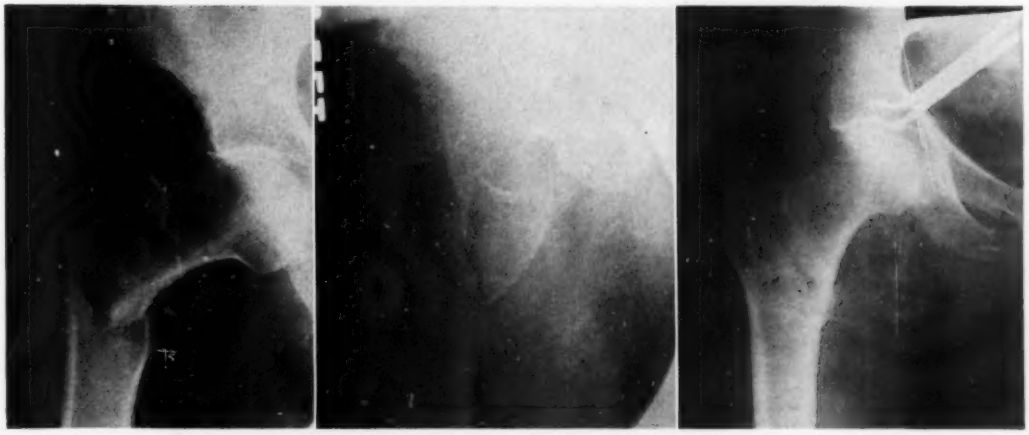
The anesthesia employed is usually pentothal® with gas oxygen or avertin with gas oxygen. We have recently used pentothal® much more frequently and curare is added later if more relaxation is required. On the day of the operation the pentothal® or avertin is given at the patient's bed. As soon as the patient is asleep, the Russell traction is removed, a Thomas leg splint is applied with traction maintained to the distal end of the splint and the patient is transported to the operating room.

A cassette holder is placed under the fractured hip on the operating room table and a sterile towel clip is placed over the inguinal ligament midway between the anterosuperior



2 3

FIG. 2. Case 1. Six months after nailing, with good union.
FIG. 3. Case 1. Two years and four months after operation.



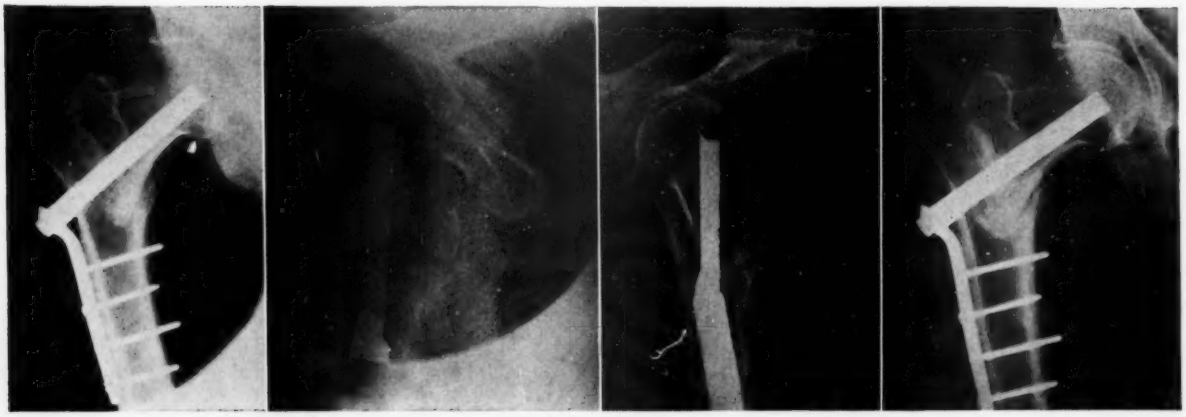
4 5

FIG. 4. Case 11. Intertrochanteric fracture in a woman of seventy-eight; on admission, April 12, 1949.
FIG. 5. Case 11. After Russell traction for five days.

spine of the ileum and the spine of the pubis. This clip is, at this point, usually directly over the head of the femur but may be adjusted if anteroposterior x-rays show it to be too high or too low. It is the point at which the nail is aimed in the anteroposterior plane.

Anteroposterior and lateral x-rays are taken to make sure of adequate reduction and to be certain that the towel clip is properly located over the center of the head of the femur. It should be pointed out here that a competent x-ray technician is an important part of the team. Clear x-rays of the femoral head and neck in both lateral and anteroposterior planes are essential, and in the obese thigh a good lateral view can sometimes be most difficult to obtain with a portable x-ray unit. The x-ray technician should have had real experience in this procedure and must be most familiar with the potentialities of the machine he is using. Nothing in this operation can be more aggravating than to have the nail driven in and be unable to obtain adequate lateral views.

The extremity is maintained with full extension at the knee and is held at the lower leg and ankle by an assistant seated on a stool at the foot of the table. In this manner the extremity may be internally or externally rotated or abducted or adducted as may be necessary during the operation to bring the fractured surfaces in close apposition. If the preliminary x-rays do not show adequate reduction, a gentle manipulative reduction is then carried out; but, as was noted before, with preliminary Russell traction this is seldom required.



6 7

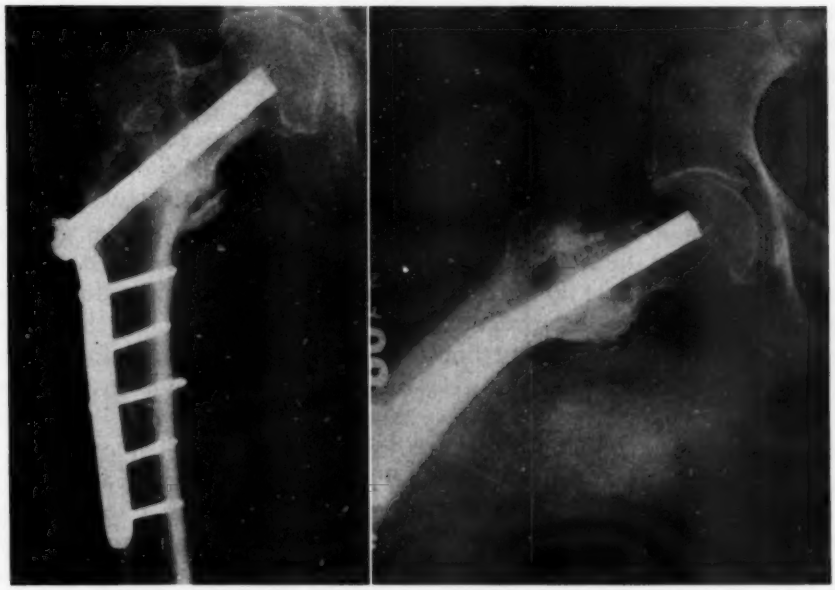
FIG. 6. Case II. After nailing with Smith-Petersen nail with Thornton extension bar.
FIG. 7. Case II. Six months after nailing showing bony union.

8 9

FIG. 8. Case III. Intertrochanteric fracture in a woman of eighty-seven; on admission, March 14, 1949.
FIG. 9. Case III. After nailing with a Smith-Petersen nail and a Thornton bar, April 8, 1949.

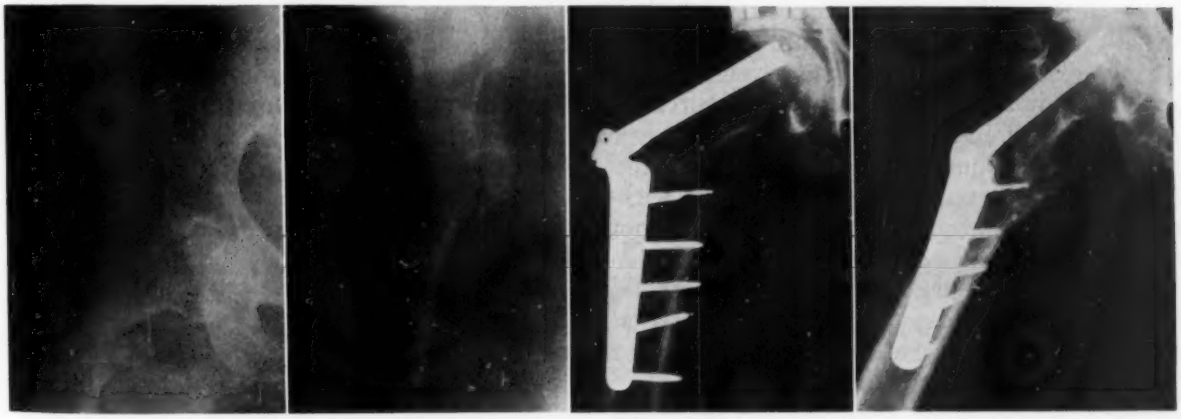
A blood transfusion is always started at the beginning of the operation and is continued throughout the operative procedure. We have found it of great value in avoiding shock. The blood is run in slowly; 500 cc. are usually sufficient for this procedure. We noted early in our experience how much easier it was to prevent these elderly patients from going into shock than it was to pull them out after shock had occurred.

The operative area is painted with a suitable skin antiseptic and draped. The nailing is carried out as a "blind nailing" through a longitudinal incision on the outer aspect of the thigh extending downward 6 to 8 inches from the greater trochanter. Vitallium® Smith-Petersen nails, extension bars and screws are used routinely. In our opinion vitallium® is the ideal metal for all bone operations due to the absence of electrolytic phenomena; also, wherever used it seems to be completely inert in the tissues. Loosening of the Smith-Petersen nail or of the screws is very seldom seen and was not observed in a single instance in this series. The nail is started on the outer side of the shaft of the femur 1 inch below the greater trochanter after breaking through a hole in the cortex at this point with a bone punch. In the anteroposterior plane the nail is aimed for the towel clip previously described. A Kirschner guide wire is not used as we believe that with our technic it is not necessary, and the danger of breaking off the wire and driving the distal portion up into the pelvis ahead of the nail is avoided. In the lateral plane the direction of the driving of the nail



10A 10B

FIG. 10. Case III. A and B, fourteen months after fracture with bony union, May 11, 1950.



11 12

FIG. 11. Case IV. Subtrochanteric fracture in a woman of fifty-seven; a large amount of comminution; on admission, February 16, 1950.

FIG. 12. Case IV. One month after nailing with a Smith-Petersen nail and a McLaughlin extension bar.

will be determined by the position of the extremity that is required to bring the fractured surfaces in apposition. If it is necessary to rotate the extremity internally to accomplish this, the nail should be kept parallel with the level of the operating table. If, however, the extremity has to be kept in a neutral position, the nail should be driven in a somewhat anterior plane to follow the normal anterior inclination of the neck of the femur as it passes from the shaft of the bone to the head. The length of the nail to be used in an individual case may be easily estimated before operation while the patient is still in the Russell traction. An anteroposterior x-ray of the hip is taken with a 1-inch lead marker held with adhesive onto the skin of the thigh just lateral to or just above the greater trochanter. The lead marker is measured on the film and, as some magnification is always present in an x-ray, it will usually be found to measure from 1⅛ to 1¼ inches. The distance from the joint surface of the head of the femur to a point on the outer side of the shaft 1 inch below the greater trochanter is then measured. A reduction in this measurement is then made in proportion to the magnification in the length of the lead marker and will give

the desired length of the nail to be used. It should be remembered that in intertrochanteric fractures the nail must protrude a short distance outside the shaft of the bone to permit attachment of the extension bar. (In nailing intracapsular fractures, of course, this protrusion is not necessary.)

Having driven the nail about three-quarters of the way in, check x-rays in both anteroposterior and lateral views are taken to be sure that the nail is traversing the neck properly in both planes. If the nail is shown not to be in proper position, it is withdrawn and reinserted. Otherwise it is completely driven home into the head, leaving enough of the nail protruding to permit attachment of the extension bar. The bar is first screwed tightly into the base of the Smith-Petersen nail and is then securely screwed to the shaft of the femur with four or five screws. The only comment necessary in this regard is that one should be sure all the screws go through both cortices. The lesser trochanter which is usually displaced in this fracture can be completely disregarded in the reduction and the nailing as it always reunites with the rest of the fracture site as callus is laid down.

The skin wound is then closed, dressings applied and the patient returned to bed without any external support. The limb is not placed in traction postoperatively as we believe this is entirely unnecessary. If the internal fixation is adequate, postoperative external fixation or traction suspension certainly is not indicated.

Early motion of the knee and hip are urged and we attempt to have these elderly patients flex the knee and hip in increasing degree from the first or second day postoperatively. Early ambulation is desirable but in the advanced age group we do not "force" them out of bed for the first five or six days. Use of the wheelchair is then started and weight-bearing is begun with the aid of the ambulatory Thomas splint about two weeks after the operation. An individual splint which breaks at the knee is made for each patient, and we are quite enthusiastic about its use. It has been our experience that a pelvic band is not necessary. If properly made so that the ring of the splint rests comfortably against the tuberosity of the ischium without undue pressure against the vulva or scrotum, the splint relieves the fracture site of most of the weight-bearing strain and is handled much more readily by these older people than are crutches. They seem to feel more secure with the splint and can be taught to walk very quickly with the aid of the mechanical walker.

Penicillin and either streptomycin or chloromycetin are started two days preoperatively and are continued postoperatively for a period of ten days. The use of these antibiotics seems to be a great factor in reducing the incidence of infection. In fact, since they became available we have had no infections. The penicillin is used in doses of 100,000 units every six hours and the streptomycin or chloremycetin in doses of 500 mg. twice a day. The average hospital stay of these patients was five weeks. Some of the patients left the hospital at the end of four weeks and none were in the hospital more than seven weeks, with the exception of the four patients in whom infections developed.

There were 132 patients treated with this method from January, 1937, to January, 1950. There were ninety-two women and forty men or an incidence of somewhat over 2:1 in favor of the female sex. No case was seen in the Negro race, probably due to their heavier bony structure. Seventy-five per cent of the fractures were in the left femur, a finding which we cannot explain. The age distribution by decades was as follows:

Age	No. of Patients
40–50	2
50–60	6
60–70	32
70–80	68
80–90	24

There were nine hospital deaths, a hospital mortality rate of 6.8 per cent (a marked reduction from the 24 per cent mortality rate in the earlier series in which the patients were treated entirely with traction). This figure included all deaths while in the hospital. There were no operative deaths as such, all patients surviving the operative procedure. The causes of death are enumerated as follows: three cases of pulmonary embolism, probably secondary to thrombophlebitis (one autopsy); two cases of coronary thrombosis (one autopsy); two cases of uremia (one patient eighty-nine years of age and another seventy-eight years of age); increasing blood nitrogen figures developed after operation in both patients in spite of adequate intravenous fluids and restricted protein and sodium

chloride intake; and two cases of infection in wounds with subsequent septicemia; both of these occurred prior to the advent of antibiotics.

There were four infections, an infection rate of 3 per cent. All of these occurred prior to 1946. Since 1946 there have been no infections in this series, undoubtedly due to the use of the antibiotics. Of the four patients in whom infections developed, septicemia developed in two patients who died, while osteomyelitis with non-union developed in the other two patients. One of the cases ultimately healed after prolonged use of penicillin and streptomycin, but with marked shortening and a poor functional result.

One hundred twenty-three patients survived the operation and left the hospital. Of these patients, 108 have been followed up for a period ranging from one to ten years. Fifteen of the cases could not be followed up. Bony union occurred in all patients followed up, except in two instances. One was the patient with osteomyelitis previously mentioned and the other was a pertrochanteric fracture in a man eighty-five years of age who refused to walk and never got out of his wheelchair.

Follow-up x-rays were taken at three-month intervals. Bony union usually occurred somewhere between the fifth and eighth month although we had one patient of forty-three who had solid bony union at the end of nine weeks. As soon as bony union could be demonstrated in the x-rays, the ambulatory Thomas caliper was discarded and unsupported weight-bearing was permitted. No further after-care relative to the fracture was necessary and no rehabilitation was required.

SUMMARY

After an experience of over ten years in treating intertrochanteric fractures of the femur with internal fixation with vitallium® Smith-Petersen nail and extension bar, we should like to urge this method as the one of choice in handling this fracture. Operative mortality is low, early ambulation is possible and with the aid of the antibiotics the infection rate is now negligible. The elderly patients, contrary to some opinions, usually stand the operation without difficulty. We do believe, however, that necessary preoperative workup and indicated treatment for certain physical disabilities should be carried out and that the operation should not be undertaken as an emergency procedure. With these precautions in mind and with familiarity with the technic of the nailing, we are convinced that the method of internal fixation is far superior and gives far better results with fewer complications and a lower mortality rate than any traction method used.

CONCLUSIONS

1. One hundred thirty-two patients with intertrochanteric fractures of the femur treated with Smith-Petersen nailing with an extension bar are reported. Fifteen of these patients were lost to follow-up.

2. The advantages of this method over traction in treating intertrochanteric fractures of the femur are noted.

3. Attention is called to the fact that most patients of advanced age withstand the operation without difficulty. The mortality rate with this method was less than one-third of the traction method which required prolonged bed rest.

4. There were nine hospital deaths, a mortality rate of 6.8 per cent. There was no operative mortality.

5. There were four infections or an infection rate of 3 per cent. There have been no infections since 1946, probably due to the use of antibiotics.

6. No cases of this fracture were seen in the Negro race. Seventy-five per cent of the fractures were in the left femur.

7. One hundred eight patients were followed up for from one to ten years. Union occurred in all but two instances. The functional results were satisfactory, with normal length and a good weight-bearing extremity; no period of rehabilitation was required.

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DISCUSSION OF PAPERS BY DRS. STIMSON, HUCHERSON AND LEWIS

Lenore Richards (Cincinnati, O.): I was extremely interested in the paper that Dr. Stimson

gave, probably because I have been in a hospital sufficiently long that I still remember the days when intertrochanteric fractures and fractures of the femoral neck were treated in a conservative fashion. We not only had the general practitioner to convince but we had ourselves to convince first. Since the service has changed and we have now been using internal fixation, we have likewise had the internists of the hospital as well as the anesthetists to convince that this was the procedure of choice.

Out setup is such, due to inadequate help in the x-ray department, that patients with these fractures cannot be treated as emergencies in our hospital but have to be put on the elective program. We prefer to do them within forty-eight hours if possible. However, some of them wait as long as a week before being treated.

All of the house staff as well as the visiting staff have been very much impressed by the fact that the patient can never be gotten into better condition than he is in forty-eight hours after admission to the hospital. If his is an uncomplicated case, without heart failure and without impending diabetic acidosis, he is never in better shape than he is at the time of admission.

Another problem has been brought to our attention. Pulmonary complications, which in the past have been called postoperative pneumonia or atelectasis, have with increasing frequency been found to be pulmonary infarcts when the postmortem examination is made. The offending thrombus occurs with great frequency in the leg that has been fractured. We believe that the frequency of this thrombosis is directly proportional to the length of time that expires between the accident and the surgery. Therefore, in the last year we have been using prophylactic dicumarol,® starting approximately forty-eight hours after surgery.

William H. Honor (Wyandotte, Mich.): I have been particularly interested in these three papers. I think Dr. Barbara Stimson has described very completely the evaluation of these patients and the care with which they must be prepared before operative procedure. With her, I fully agree that no time should elapse before nailing. At our hospital we are very particular to see that our patients are carefully gone over by a competent internist.

Dr. Hucherson has given a beautiful description of intramedullary fixation of femoral shaft fractures. I am sure that if his technic is closely followed, we shall do much better work. Certainly, when one goes wrong it is usually an error of technic.

Dr. Lewis was handicapped due to lack of time. Previously I have heard a more detailed description by him of his method of hip nailing. With his permission I should like to emphasize some of the things that he has so clearly described: The first of these is Russell traction which at our hospital we now use routinely with excellent results and a shortening of the operating time due to the elimination of the Leadbetter maneuver. One of the things Dr. Lewis emphasizes is proper reduction of the fracture and I think that is most essential. After reduction and insertion of the nail Dr. Lewis insists on further impaction of the fracture. His results are unusual. He has a most imposing list of well patients. On admission our patients are immediately placed in Russell traction, using a weight of 10 to 15 pounds, depending on the musculature of the patient. We have noted a reduction of the fracture in a few hours. This reduction is maintained until the patient is taken to the operating room.

We use a Johannsen modification of the Smith-Petersen nail held in place by a Thornton flange using four screws. Dr. Maibauer and I have one objection to the Johannsen nail, i.e., it is apt to split the cortex of the femur when it is driven home. As I have stated, we believe that we should be very careful to see that we have as nearly as possible an anatomic reduction and that the nail is placed well into the head of the femur. In the intracapsular fracture the proximal fragment is not so apt to rotate if a Johannsen type of nail with a 22-degree angle of the flanges is used. As a further safeguard against rotation, the proximal fragment is transfixed with a Kirschner wire into the acetabulum.

Colonel Milton S. Thompson (Fort Sam Houston, Tex.): The excellent papers by Dr. Stimson and Dr. Lewis leave little with which to disagree. We do not consider our hip fractures emergencies the way Dr. Stimson does, partly because of a backlog of surgery and partly because by several days in traction the fracture is reduced, the patient's fluid and protein balance is corrected and operative site "prepped."

We use a lateral exposure of the fracture itself which I think is widely used but rarely mentioned. One can always palpate and frequently see the fracture site, actually doing an open reduction and eliminating the necessity for guide wires or many x-rays.

About the intramedullary nails, we have used them in femurs for only two years. In that time we have had 192 fractures of the shaft of the femur and have used the intramedullary nail in forty-five.

Dr. Hucherson spoke of diameters. We no longer measure the diameter of the medullary cavity but use narrow nails. Soeur pointed out that because the femur curves in two planes a smaller nail holds tightly, and it usually does. Even if it allows lateral displacement, a strong callus forms. We use nails of 9 and 8 mm. in diameter.

We have had various types of nails break and bend.* In one case a V-shaped nail was used which was too short, not driven in far enough and inadequately protected. Ten months after insertion it broke. The patient now has another nail.

In another case a "cloverleaf" nail was well nailed but, in retrospect, must have been inadequately protected. The nail broke nine months after insertion and was replaced. The patient was discharged to full duty four months after renailing, with clinical and x-ray evidence of union.

In another case a Hansen-Street type of nail was used which bent. In spite of its bending the fracture healed. The angulation caused no disability.

JOHN E. MCDONALD (Tulsa, Okla.): These have been very interesting papers. I would like to mention just one or two things relative to fractures of the neck of the femur and intertrochanteric fractures.

Down in Oklahoma we are in the sticks, but it seems that our general practitioners in the small communities have learned the importance of treating fractures of the neck of the femur and upper end of the femur at an early date. Usually these people call us immediately after the fracture occurs and want to know how soon we can fix it. Out greatest problem is trying to take care of it in the community where the patient lives. We find that this is an extremely difficult problem because you have to be the internist, the anesthetist and the surgeon.

We have found in these cases that it is highly advantageous to use spinal anesthesia if you have a competent nurse to watch the patient. We can turn the patient, give him the anesthetic, turn him back and reduce the fracture with the least possible trouble. We have found that it works very well.

I want to compliment Dr. Lewis on the fact that he uses blood and fluids because we find it is highly advantageous in these elderly people.

With regard to the intramedullary nails, it has been my experience that it is important to know the exact length of the nail and, more or less, the exact diameter that is necessary before operation. We have devised a metal rod with little notches on it in order to measure the exact length of the nail. We put it alongside the femur in order to determine the exact length at the time the femur is x-rayed. We also determine the diameter. We find that this has been of extreme advantage to us and we have avoided a considerable number of difficulties that occur when we do not know the exact length of the nail.

It is important that the length is accurate. If it is not accurate, I think that is one of the principal reasons why we have receding of the nail. We have had one or two of these arise, and because of that it gives the patient the additional trauma of another operation.

We have found, too, that it is highly advantageous in those people who have multiple operations or comminuted fractures, those people who have internal injuries who need to be maneuvered around in bed. I can think of one particular patient who had a fracture of the femur, two fractured humeri, a fractured clavicle and marked injury to her chest, with decompression of her lung. It was important that this patient have some means of being turned in bed.

DANA M. STREET (Memphis, Tenn.): Dr. Hucherson is to be congratulated upon his large series of cases and excellent results. He did not discuss the question of comminuted fractures probably for lack of time.

Baylor originally claimed that these cases were not suitable for this method. However, in the latter part of his book he described the use of annular sutures in fractures without very much comminution.

Annular sutures quite frequently allow some slipping of the fracture site and overriding. Such fractures we prefer to treat with supplementary transfixion screws. These screws are inserted tangentially so as to miss the nail, and many times they are in cortex for their whole length. One has to be careful not to hit the nail with the drill point; otherwise, it will frequently break.

Dr. Hucherson was more successful in avoiding infection than I. In a series of seventy cases we had two infections. One appeared soon after the nailing; the other appeared after removing the nail, about one year after the nailing. The former was our third case, nailed about five years ago, in which a full-blown infection developed. According to Kuntscher one should leave in the nail, and according to Dr. Eggers we can get union in spite of infection provided there is bony contact. We were wrong on two counts in treating this patient: We pulled the nail very soon after the infection developed or about two months after nailing, and weight-bearing was not permitted. In spite of this, however, he went on to eventual union with no shortening.

One hears references to massive callus in this method of treatment. This is frequently more in the nature of a myositis ossificans and the result of extensive muscle trauma.

HARRISON L. MCLAUGHLIN (New York, N. Y.): Few modern surgeons will disagree with the contention that intertrochanteric fractures deserve internal fixation, not only for the benefit of the fracture but also as a means of reducing morbidity and mortality through minimization of the physiologic penalties of postoperative stasis in the elderly patient. What benefits accrue from a delay of five

* Dr. Thompson showed slides illustrating the cases cited.

or six days before operation? As a rule these patients are in the best condition at the time of admission and deteriorate rapidly from then on until the fracture is stabilized. Their physical evaluation requires hours rather than days, and the only valid organic justifications for delay, with rare exceptions, consist of the need for digitalization or the stabilization of uncontrolled diabetes.

Following operation Dr. Lewis advocates the use of a so-called ischial weight-bearing brace. No such brace entirely removes weight from the hip; all act as fulcrums tending to lever the fractures into varus, and most are heavy and cumbersome for the elderly patient to manage. If partial weight-bearing is to be allowed, why not give the patient crutches and allow the foot to touch the ground? If no weight-bearing is to be allowed, why not use crutches without weight-bearing or a wheel-chair until healing occurs at the fracture?

DENMAN C. HUCHERSON (closing): I wish to thank the discussors of my paper. There is only one point that has not been brought out which I would like to mention. We believe that medullary fixation definitely delays union. For that reason we believe that supplemental bone should be used in more cases. With a bone bank this can be readily accomplished without great additional risk to the patient. We have routinely used it in cases of delayed and malunion with gratifying results and we believe that in the future supplemental bone will be employed in more of our fresh femoral fractures.

W. LARRABEE (Hartford, Conn.): I did not plan to inflict myself on you twice, but Dr. Stimson's paper is so much to the point that I want to say a word about it. In the first place, the title is intriguing.

I think along with this, to mention Dr. Lewis's points about these old people, when they live that long they have something that you and I probably do not have; it is amazing how well they stand their surgical treatment.

The third point is that I cannot see why it takes us longer than thirty-six hours to evaluate these people. Those doctors around my community of Hartford who do not agree with me are now being pushed by the internists and general practitioners to operate upon patients at the earliest possible moment.

OSCAR P. HAMPTON, JR. (St. Louis, Mo.): Dr. Stimson was kind enough to send me a copy of her paper. I enjoyed it thoroughly and consider it quite a privilege to discuss it.

I did not think I had much to argue about until Dr. Lewis gave his paper, but that gives me the chance really to agree with Dr. Stimson. I cannot see, as Dr. McLaughlin stated, the advantages of delay. In St. Louis when operating upon a fractured hip the most expedient time to the doctor is selected, providing the nailing can be done within forty-eight hours. It appears to us that any delay past forty-eight hours is not of benefit to the patient.

I would like to add one remark about Dr. Hucherson's paper. The intramedullary fixation of near transverse fractures of the shaft of the femur is in the same stage as Smith-Petersen nailing of hips was in 1936. It is *the* treatment, and the members of this organization should realize that other methods are inferior. If the fracture can be stabilized with intramedullary fixation, that is the preferable method of management.

PRESTON A. WADE (New York, N. Y.): Dr. Speed said that ten years ago Dr. John Caldwell gave a talk on intertrochanteric fractures at Hot Springs. At that time I advocated intertrochanteric nailing in my discussion and some of the doctors from Boston gave me a terrific going-over, so I am standing up to vindicate that a little bit now.

I want to congratulate Dr. Stimson and Dr. Lewis for their fine papers. I think everybody agrees now that the treatment for intertrochanteric fractures is nailing.

There are, however, two or three things I should like to say. First, my colleague, Dr. McLaughlin, has already mentioned one, that is, the walking caliper. I think the walking caliper postoperatively is not necessary and is a definite hindrance. The walking caliper prevents the patient from being ambulatory. I think what the doctor wants to do is to get the patient walking and get his knees and ankles in motion. I believe the brace is not necessary.

We have used the Moore plate that was mentioned, too, and we find it cuts out at the neck so we stopped using it. Then we tried the Neufeld plate and had it break on several occasions. We now find that the McLaughlin nail is the best and we are using that now.

GEORGE J. CURRY (Flint, Mich.): I cannot let this opportunity go by without paying my respects to a very fine Poughkeepsie surgeon who has done such an excellent job of presenting the basic principles relative to the education of the profession in recognizing the seriousness of hip fractures.

I understand from a little investigation that prior to the Stimson era in Poughkeepsie fifteen hips were pinned over a period of fifteen years. It seems to me, therefore, that Dr. Stimson has done pretty well to have treated forty-two in a little less than two years with the excellent mortality rate that she has.

Her troubles are duplicated, I am sure, in many communities of this country. In Flint, Michigan, we have treated 700 fractures of the hip since the first one was pinned in November, 1937, and I can assure Dr. Stimson that at the beginning we had the same difficulty she is having now.

Now, and for a long time past, the internist and the general practitioner seem to be eliminated for the most part from the situation, and the family demands that this very excellent method of management be given the elderly patient with a fractured hip.

BARBARA B. STIMSON (closing): Well, I think we started something. I am surprised I was let off as lightly as I was on my title. I want to thank the discussers, and I know they will forgive me if I do not take up the points individually because there were so many. There were some valuable suggestions. There are two things I would like to say, however.

We have not so far been forced to give anticoagulant therapy although we have watched very carefully for any evidences of thrombosis.

One of the reasons, probably, why we do hips as emergencies is because we have trained the hospital so we can get the cases of hip fractures in at night. We would have a great deal of difficulty breaking in on the regular operating schedule the next morning. It works better.

I should like to congratuate Dr. McDonald on his general practitioners. He must have them extremely well trained in Oklahoma. But is there not a hospital to which he can take all hip fractures, even if they have to be transferred later, so that he does not have to be internist, anesthetist and surgeon all at once? We discovered, again, that education works and that people who want to have their hips pinned can go to one hospital where the setup is with x-ray, anesthesia and so on. It is all laid on; it is far better, I think, than taking the surgeon to all the small areas in the vicinity. The patient can easily be brought to the surgeon. I do think that it helps.

I want to thank you all for your very gracious discussion.

KENNETH M. LEWIS (closing): In presenting this paper it was my desire primarily to urge internal fixation in the treatment of intertrochanteric fractures of the femur. A difference of opinion as to whether one should operate upon these people immediately after their admission to the hospital or after a lapse of a few days was to be expected. I definitely believe, however, that a complete medical checkup should be done on each patient before the operation. If it is possible to accomplish this in twenty-four to forty-eight hours, well and good. It has been my experience, however, that it takes three to four days before all the laboratory reports are available.

I wish to stress again that the operative procedure should not be undertaken as an emergency in the middle of the night or possibly over a weekend when one is working with a skeleton operating room force and with an x-ray technician who may be inexperienced in this type of x-ray technic.

I still believe that the ambulatory Thomas splint as a means of support is worth while as I have seen any number of these elderly patients who could not, or would not, adequately use crutches. They seem to have more confidence when the brace is used and we have not seen coxa vara deformity following its use.

BASIC PROCESSES IN HEALING*

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As discussed herein, healing connotes the restoration of supportive tissue of the mesenchyme, that is, connective tissue. Consideration of special connective tissues such as bone and cartilage will be indirect. Correlated healing of other special tissues such as dermal epithelium or mucosa will be implied.

The orientation of this paper may be given by citing the preface of the book by R. Leriche and A. Policard[1] who gave as their reason for writing approximately ten years of clinical and experimental observation. They wrote, "The problem of osteogenesis has passed through many phases. It has been histological and surgical and at the present time it is above all, chemical. It is useless now for histologists to repeat what has been done so many times, and for surgeons to experiment on periosteum, on grafts and on the osteogenesis of repair. It is now the turn of the chemists and physicists. They alone can open up new horizons by giving us some of the certainties we lack. When they have solved certain pending questions, it will be possible to resume with profit the studies of the past. We can then progress and, perhaps, have bone formed at will, accelerate the union of fractures and prevent the pathological or physiological rarefactions of bone, but for this to occur, it is necessary for us to ask them definite questions."

It is our intent to clarify some questions on the basis of work initiated fifteen years ago. The sustaining thesis has been the paramount importance of local factors in the healing of tissue.[2] Evidence has gradually accumulated which, although admitting the importance of local, chemical and physical forces, shows that under special circumstances, the general metabolism has considerable influence.

CELLS AND CELL PRODUCTS

It is well to restate briefly what takes place at the site of injury. There is laceration of tissue, hemorrhage and tissue necrosis. This immediately starts the cycle of repair by increasing capillary permeability in the form of a simple polypeptide,[3] an intermediary breakdown product preparing the way for polymorphonuclear infiltration. With increased lactic acid formation as a result of the anaerobic respiration in acutely injured tissues and unaugmented alkali reserve, the hydrogen ion concentration moves toward pH 6.5 or below. In this environment the leukocytes do not survive well and the secondary phase of lymphocytic infiltration is set up. Considering the disturbance of fluid balance in early inflammation, permeability studies using the polypeptide,[5] leukotaxine,[3] revealed that corticosterone and adrenal extract prohibited increase in capillary permeability, but desoxycorticosterone actually increased it. Adrenal-cortical extract almost completely stopped increased capillary permeability. This may not seem important except that cortisone can for a time virtually stop completely the reactivity of tissue to injury[7] and temporarily inhibit granulation tissue and retard the healing of fractures and wounds.[8] Moreover, the response of rats to acute stress[9] is proportionate to the decrease of ascorbic acid in the adrenal and is interpreted to mean that elaboration of ACTH is at a rate inversely proportional to the concentration of the cortical hormones in the body fluids and according to the requirement of peripheral tissue cells for cortical steroids. Knowledge of the relationship of the steroids to cells is relatively new, but the literature is too deep to cite except briefly. Desoxycorticosterone can be changed into a glycogenic material *in vitro*.[10] Kendall showed the influence of the adrenal cortex on glycogenesis.[11] The corrective action of Compound E and corticosterone in the abnormal carbohydrate metabolism of Addison's disease[12] is clear. Moreover, cortin-like compounds produce glycosuria and even severe ketonuria.[13] In passing,

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the profound influence of the steroids on the excretion of electrolytes[14] should be cited with the equally important influence that they have on the inhibition of increased permeability due to hyaluronidase on membranes and the neutralization of their effect by products released *in vivo* by rabbits exposed to the alarm stimulus.[15]

As the progress of events in the response of tissue to injury moves on, the infiltration of lymphocytes and macrophages increases, and a shift toward the acid hydrogen ion range causes the neutrophiles to disappear. Soon fibroplasia becomes manifest and a later phase of healing supervenes. Although fibroplasia is probably most manifest under the microscope, correlated with it are histochemical events of the greatest importance at this stage of healing.

FIBRILLAR MATRIX

The first fibrillar matrix to form in injured tissue is the fibrin clot. Without it, hemorrhage becomes uncontrolled and the early formation of a clot is impossible. This in turn can prevent the systematic infiltration of cells. The early observations on fibrin formation[16] have been expanded. Recently,[17] working with purified bovine fibrinogen and thrombin, using the electron microscope, the close correlation of hydrogen ion concentration and effective clotting has been shown. A clot formed at pH 6.3 produces strong, well formed fibrils which show poorer and poorer polymerization and structure moving toward a pH of 8.3. Later studies[18] indicate that through the action of thrombin, fibrin molecules are polymerized to form needle-shaped, crystal-like protofibrils which become aligned to form strands by lateral association. The integrity of the unit fibrils is maintained in the unit strand.

Studies of the general response of blood fibrinogen[19] to cold, fasting and adrenalectomy indicate that fasting for twenty-four to seventy-two hours may depress, although not always significantly, the fibrinogen concentration in rats. The trauma of nephrectomy increases plasma fibrinogen. This increase is unaffected by fasting. Exposure to cold alone does not affect the fibrinogen level. Total adrenalectomy greatly decreases the fibrinogen response to the trauma of nephrectomy. The acute stress of exposure to cold increases the rate of elaboration of ACTH by the pituitary. As previously mentioned, other steroid hormones[9] suppress this response to acute stress. Estimated in terms of suppression of the stress response numerically, the effect on the pituitary by Compound E is as 4, equal to 17 hydroxycorticosterone 4, corticosterone 1, desoxycorticosterone acetate ½ and progesterone 1/50. It is believed[19] that fibrinogen metabolism is influenced by the adrenals. Adrenalectomized rats are unable to catabolize protein, but adrenal steroids[20] convert protein to carbohydrate.

FIG. 1. Electron micrograph of collagen mat from nine-day tissue culture. Printed by permission of K. Porter and P. Vanamee, Rockefeller Institute for Medical Research.[21]

In a tissue culture when the fibrin clot begins to dissolve and the cell population gets scanty, collagen fibrils begin to form. Studying these with the electron microscope reveals[21] that unit fibers 500 Angstrom units in diameter do not vary appreciably in diameter although the ends may taper to 50 A. or less. (Fig. 1.) The small diameter fibrils carry striations of 270 A. Larger fibers show striae in groups of three in a 650 to 800 A. spacing. The larger fibers have a characteristic periodicity of 640 A. units.[22] The cross striations from human skin collagen are grouped in composites of six bands.[23] Some of the observed differences in the spacing of striations and their number may be accounted for by differences in preparation technics. In studying human skin collagen[23] reference is made to background interfibrillar

FIG. 2. Eight-day rabbit callus; the dark areas are metachromatic and represent mucopolysaccharide (s) in healing granulation tissue. Toluidine blue stain; low magnitude. Wratten No. 11 and Wratten B No. 58 filters. Reprinted by permission of the Society for Experimental Biology and Medicine.

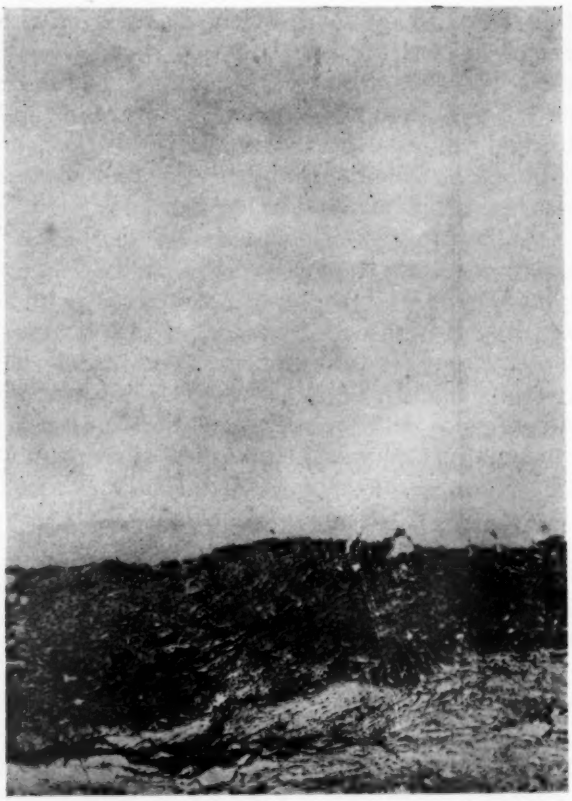


FIG. 3. Eight-day callus from cortisone treated rabbit. Note absence of cartilage, suppression of granulation tissue and meager response to injury. Hematoxylin and eosin stain; low magnification.

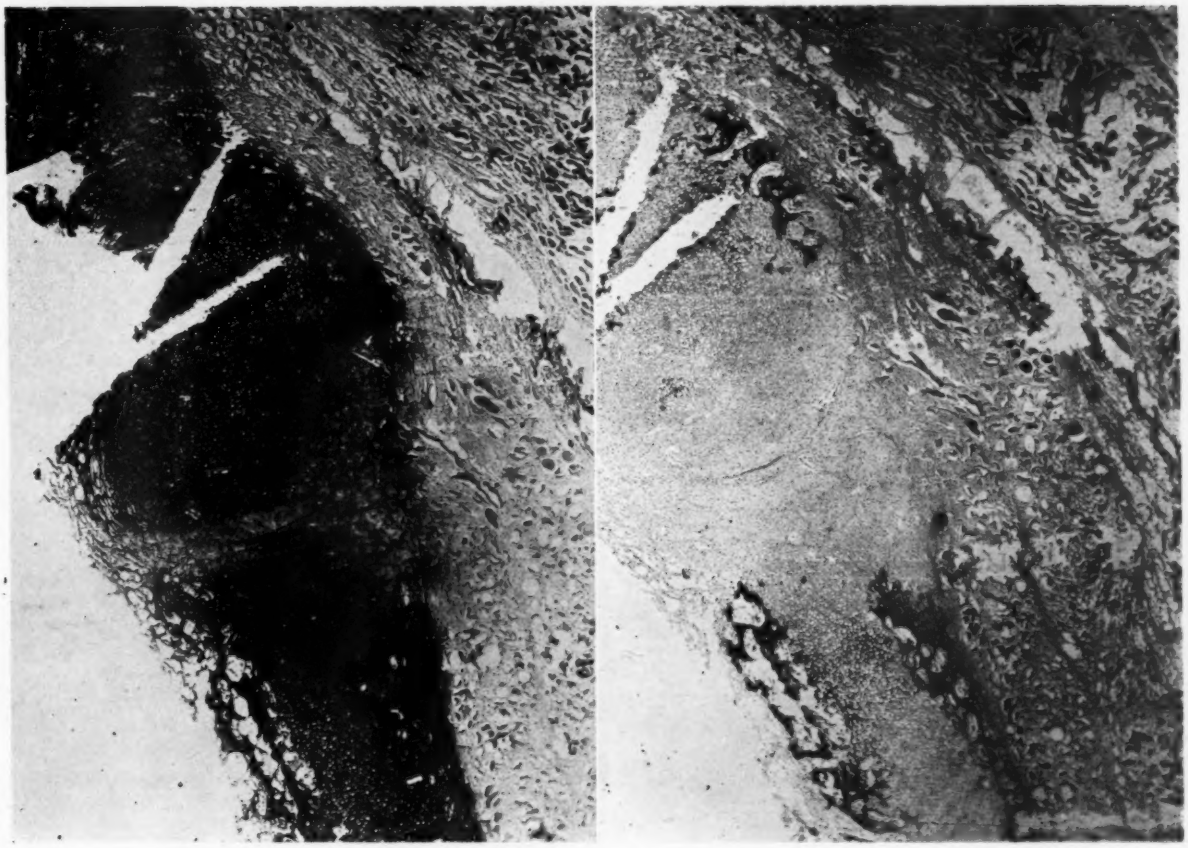
material beyond the resolution of the electron microscope, although in the tissue culture studies entities larger than collagen fibers are mentioned as possible components of the interfibrillar matrix or the ground substance to which we now come.[22,24]

GROUND SUBSTANCE OR INTERFIBRILLAR MATRIX

Moving into the interfibrillar spaces in which molecular aggregates may be beyond the resolution of the electron microscope, we go from the realm of confusion to regions of chaos. Here, our observations rest mostly on indirect evidence and histochemical technics. Our interest centered here because of the obscurity of the metabolism of calcium, phosphorus and carbonate compounds which are the means of the transformation of soft tissue healing to the healing of fractures. Histochemical observations in the healing of fractures[24] showed what we believed to be acid mucopolysaccharide(s) present in the granulation of repair. This material which may well consist of a related series of compounds is in the interfibrillar spaces of early granulation and cartilage. Its presence parallels the fibroplasia of healing granulations,[25] has a close time relationship with maturing of fibrous tissue and almost disappears in fully mature fibrous tissue or bone. Its formation is almost completely suppressed by cortisone,[26] except in the dermis, which also greatly delays the healing of experimental fractures.

The profound suppression of the reactive response of tissue to injury by cortisone[7] not only inhibits the formation of granulation tissue but virtually stops the formation of the metachromatically staining ground substance.[26] (Figs. 2 and 3.) Phosphatase activity parallels the suppression of fibroplasia, and the meager reparative tissue appears defective in development, as in profound Vitamin C deficiency. (Figs. 4 and 5.)

The chemistry of tissue destruction and repair which goes on in the primordial interstitial spaces of granulation tissue is not confined to wounds alone but is present in the protean tides



4 5

FIG. 4. Eight-day rabbit callus; alkaline phosphatase activity indicated by dark areas of the healing tissue. Comori technic; low magnification.

FIG. 5. Eight-day rabbit callus; alkaline phosphatase control. Gomori technic; low magnification.

of living, aging and disease. Diseases of the collagen system, such as scleroderma, rheumatic fever and lupus erythematosus[27] have as a common denominator changes in the fibrillar and interfibrillar components of connective tissue. Tonsillitis, scarlet fever, nervous strain and cold have been grouped as incitants to set off the adaptive[28] response of the adrenal cortex. Correlating these are pathologic changes in the intercellular matrix. It is no longer sufficient to speak of fibrinoid degeneration in the supportive structures of the body[29] but of acid mucopolysaccharide(s) in the ground substance(s). In the granulations we have studied, there are increased phosphatase activity, lysozyme, sulfate radicals and implied phosphate enrichment.[30] The fixation of the sulfate radical by granulation tissue *in vitro*[31] and histochemical study of polysaccharide(s) in diseased skin[32] leave very little of the body out. The distribution of the intercellular matrix throughout the body includes all of it.

November 15, 1950

SUMMARY

Some of the physiology of injury and repair has been discussed. Observations on the "ground substance" of healing tissue are reported. Supportive tissues, because of their distribution throughout the body, participate in virtually all phases of the body economy, whether normal or diseased.

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BONE REPAIR IN RATS WITH MULTIPLE FRACTURES*

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EXPERIMENTAL animals with multiple fractures provide special conditions for basic investigations in bone physiology and ideal circumstances for objective study of a variety of questions in everyday treatment of extensive bone injuries. From clinical observations on patients with multiple fractures it has been assumed that repair of any one bone is retarded. A specific bone-producing hormone has been postulated which could be depleted by excessive demands for new bone.[4] There is, however, as yet only presumptive evidence of a humoral osteogenetic factor.[1] Roche et al.[14-16] and Morgue[12] suggested the possibility of a "unified systemic reaction" of the skeleton in fracture healing. The possible need for mineral and other dietary supplements for bone healing in multiple fractures has also often been suggested to every surgeon by his patients. The factor of the age of the individual in callus formation or delayed union is also usually considered but is difficult to evaluate. The data in the experiments to be presented are largely gross observations on tolerance to injury and on bone healing, including certain aspects of the changes in blood and bone ash. Multiple fractures were made in young and old rats in various ways. The fractures were produced in one or more different bones in one extremity, in both hind limbs or in all four extremities, at single or at repeated operations.

MATERIALS AND METHODS

Eighty-two white laboratory rats (Wistar, Sprague-Dawley and mixed strains) were divided into six groups and treated as described later. All the fractures were made by manual osteoclasis, under ether anesthesia, simply by bending the bone across the edge of the side of an ordinary sheet metal cage. The diet consisted of "Lab Chow Checkers" and water which were made easily accessible in the floor bedding.

Group I: Simple fractures were made in eight immature rats (age ten weeks) in twenty-two of the long bones of all four extremities. One or two additional animals in this and the following experiments received only one fracture of the mid-shaft of one tibia and were designated controls.

Group II: Ten adult rats, extracted from old breeding stock, one or more years of age, were treated similarly.

Group III: Ten rats, age ten weeks, were also subjected to a total of twenty-two fractures, but the injuries were double fractures made in the upper and lower thirds of the long bones of only the lower extremities. This produced a total disability somewhat less severe than in those animals with fractures in all four limbs.

Group IV: In seventeen immature rats, age ten weeks, a fracture of one or two of the long bones was made every five days, until there were approximately forty-four fractures healing in sequence in all four extremities over a period of three months. The right tibia was reserved as a test bone and fractured at the end of the experiment.

Group V: Twenty-two adult rats were treated in the same manner as the animals in *Group IV*.

Group VI: Thirteen young rats, age ten weeks, were given a fracture of the femur, the tibia the fibula and all the metatarsal bones. Every five days the fracture callus was refractured in an attempt to retard union.

A roentgenographic survey of the skeleton was made at ten-day intervals. The right tibias were excised and prepared for gross and spot-check histologic examinations. The levels of the serum calcium and phosphorus were measured by standard methods. The lumbar

* From the University of Chicago, Department of Physiology, Chicago, Ill. These investigations were aided by grants from the Division of Research Grants and Fellowships of the National Institute of Health, United States Public Health Service; from the Josiah Macy, Jr., Foundation and from the Wallace C. and Clara A. Abbott Memorial Fund of the University of Chicago.

1 2

FIG. 1. Fracture of the right tibia at thirty days; the fracture is united but does not yet show new bone between the cortical ends. This is the end point used in the healing schedule presented in Table 1.

FIG. 2. Fracture of the left tibia at sixty days of healing; x-ray shows further consolidation of the bone structure of the callus and new bone formed between the cortical ends.

spines were thoroughly trimmed of soft parts for determination of the per cent ash on the dried, fat-free chain of vertebrae intact with discs. The technics used were the same as in previous studies from this laboratory.[21–25]

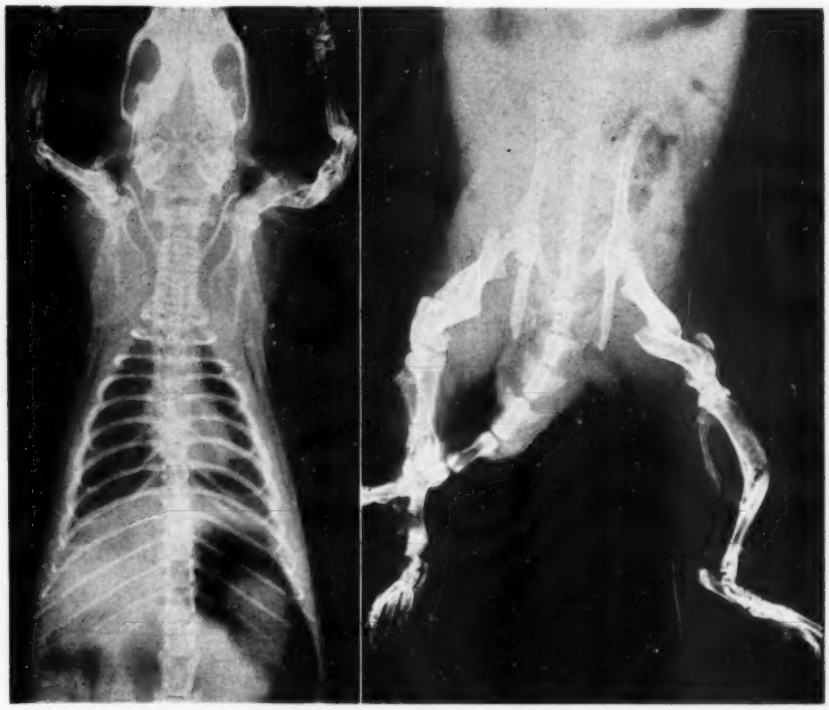
RESULTS AND CONCLUSIONS

Process of Healing of Twenty-two Long Bone Fractures in Growing Rats (Group I). A few preliminary operations on five or six animals demonstrated that a rat could tolerate the disability of twenty-two fractures without difficulty in a majority of cases. The extensiveness of the trauma of twenty-two fractures in all four extremities was expected to create conditions unphysiologic and unacceptable for a study of bone healing. The mortality of the operation itself, however, was remarkably low and the experiment was conducted when it was found that fracture healing did occur and was qualitatively normal. The delayed constitutional effects of the extensive injuries were quite severe. Of a litter of eight, all survived the operation and initial trauma and lived for four days; however, four died at some time within a period between four and eleven days after the injury. During this interval the living animals as well as the dying* and the dead were found to have lost from one-sixth to one-fifth of their body weight. The four survivors began to gain weight two weeks postoperatively and lived until the seventieth postoperative day, when the experiment was concluded. At the time, however, only one rat had exceeded its original body weight. The others weighed from 10 to 30 per cent less than control rats with one fracture. The systemic changes in animals following bone injuries, the traumatic shock and the metabolic pattern of recovery from trauma have been described in similar though less extensively injured animals[3,6,12,17] and will be discussed later in relation to bone healing.

The objectionable unphysiologic nutritional conditions in a severely disabled animal appeared to be without significant effect upon the process of healing of fractures. The normal formation of callus, the volume of the new bone formation and the time of occurrence of union were the same as in control rats healing only one fracture who showed no appreciable weight loss or significant metabolic disturbance. The average healing time to develop union for immature rats with either single or multiple fractures was the following: tibia, twenty-five days; humerus, thirty days; radius and ulna, forty days; femur thirty to forty days. (Figs. 1, 2, 3 and 4.)

Process of Healing of Twenty-two Fractures in Adult Rats (Group II). The tolerance to the operative injury appeared to be greater and the subsequent weight loss was less in adult rats than in the ten week old immature animals. The mortality during the first two weeks of the experiment was 20 per cent. Seventy days later, at the conclusion of the experiment, all of the survivors had regained their original body weight. The time of union of the fractures usually occurred approximately five days later than in the corresponding bones of the similarly treated immature rats. This was noted occasionally in fractures which were relatively undisplaced. In the healing of the displaced fractures there was an even greater difference in the time interval for union in young and old rats. The immature animals showed great masses of bony callus

* Rats in poor condition sacrificed for autopsy.

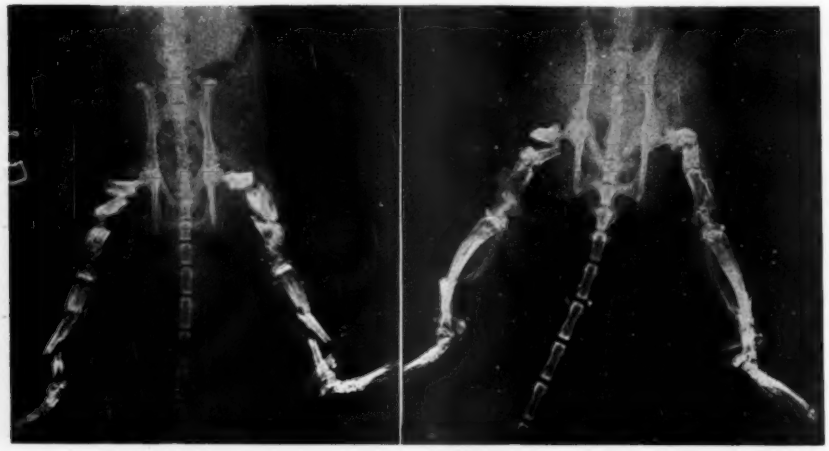


3A 3B

FIG. 3. Young adult rat approximately ninety days after twenty-two fractures were produced in all four extremities at a single operation. With the possible exception of the overriding displaced fracture of the left femur, all of the fractures have united in the normal period of time.

4A 4B

FIG. 4. An old rat approximately ninety days after twenty-two fractures. With the exception of the displaced fractures of the right humerus and left femur, all of the fractures united in the normal period of time.



5A 5B

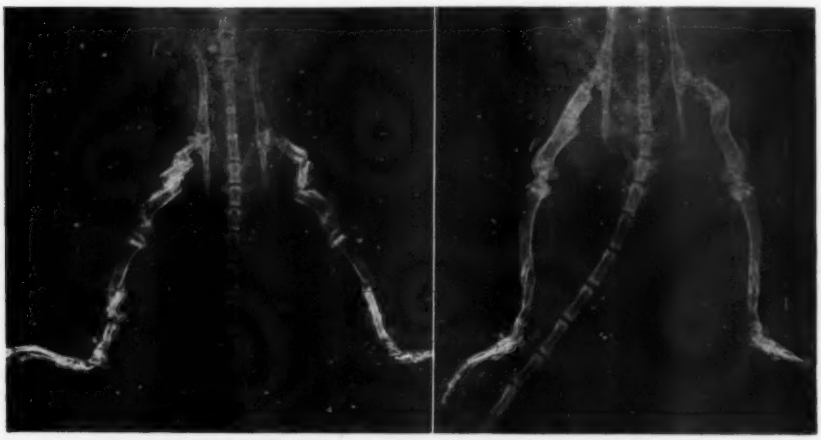
FIG. 5. A, hind legs of an immature rat, ten days postoperatively, showing bilateral double fractures of the shaft of the femur, tibia and fibula. There is new bone in the callus of the proximal fracture lines of the right and left tibia. At this early stage of healing the fracture lines show little or no new bone by roentgenographic examination. B, hind legs of the same animal as Figure 5A at twenty-one days of healing. Note the consolidation of the proximal fracture lines of the tibia, the bridging of the distal tibia and distal femoral fractures by new bone, the relatively slight amount of new bone in the proximal fractures of the femora.

bridging wide defects as early as three weeks after the injury. In adult rats the fracture gap, in corresponding bones, particularly in the femur, was often not crossed by the fifth or sixth week of healing and the callus was usually not voluminous. Whether displaced or undisplaced, the initial period of the appearance of subperiosteal new bone formation occurred approximately five days later in the adult. The time interval between the bone injury and the gross osteogenetic reaction of the periosteum in young and old animals was the same in controls with one fracture as in animals with multiple fractures.

Non-union was occasionally found in the femora of adult animals. The femoral fractures were also often more widely displaced than other bones. Side-to-side healing or malunion frequently occurred, but non-union was noted particularly in the proximal portion of the shaft of the femur whenever there was wide displacement of the bone ends into separate muscle compartments of the thigh. Angulation of fragments, however, did not seem to discourage prompt union.

Double Fractures of the Long Bones of the Hind Limbs (Group III). Twenty-two fractures were produced at one operation by manual osteoclasis of the upper and lower ends of each of the long ones of the hind limbs, sparing the forelimbs. The tolerance to the injury was not significantly greater than when the injury was distributed over the entire skeleton. The critical period of survival was the first two weeks after the injury just as was noted in experiments with fractures in all four limbs. The over-all mortality was 40 per cent. In the repair of two diaphysial fractures, with an isolated fragment of shaft, one fracture line often healed in the same time as a single fracture of the mid-shaft. In the tibia the upper fracture line usually united first; in the femur the distal fracture line united first and the proximal fracture line of the femur very frequently was the site of non-union. The shape of the bones became greatly distorted. There was great variation and no apparent regularity in the time interval of union. (Figs. 5, 6 and 7.)

Fractures Produced in Series in All Four Extremities in Immature Rats (Group IV). Due to the undesirable circumstances in dealing with severely disabled animals, experiments were designed in which fractures were produced by repeated operations, one or two bones at a time. A five-day period was found to be sufficient for recovery from both the deleterious and disabling effects of each injury. By this method it was possible to prepare animals having as many as forty-four frac-



6A 6B

FIG. 6. A, another case of double fractures of the long bones of the hind legs in a young rat at ten days of healing. The sequence of healing of the fractures is the same as Figure 5A and was consistently found in the healing of double fractures. B, the same case as shown in Figure 6A at fifty days of healing. This is an exceptional case in which the proximal fracture lines of the femur were angulated but not greatly displaced and united in the normal period of time.

7A 7B

FIG. 7. A, hind legs of a young rat, a littermate of animals shown in Figures 5 and 6, at twenty-one days of healing. The sequence of union of the double fractures was consequently in the following order: first in the proximal tibia and distal femur, later in the distal tibia, and least advanced in the proximal femur. B, hind legs of the same animal as shown in Figure 7A at sixty days of healing. All the fractures have united except the left upper femur which appears to show only slight callus formation and the right upper femur which shows a pronounced non-union with sclerotic bone ends. Note, however, the extreme overriding and displacement in the latter fracture.

tures in different stages of healing within a period of ninety days. There was no critical interval during the first two postoperative weeks such as was noted in previous experiments wherein large numbers of the animals would be expected to die. When fractures were produced in series, the rats did not lose weight, grew at a normal rate, mated and delivered normal young during or at the conclusion of the experiment. The main difference between these rats and normal control littermates with only one or two fractures, was that the average animal weighed approximately 10 gm. (5 per cent) less at five and a half months of age.

The changes in the blood serum, bone ash and the rate of fracture healing in these animals are summarized in Table 1. Complete skeletal x-ray surveys at ten-day intervals showed normal callus formation and union of

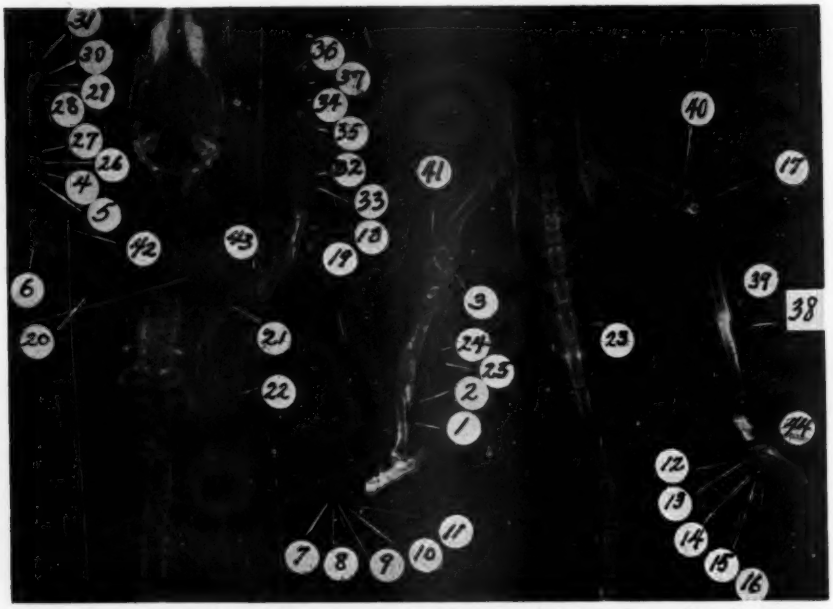


FIG. 8. Roentgenogram of a young rat with approximately forty-four fractures produced in series at five-day intervals at eighteen operations within a period of ninety days. The fracture of the left tibia (indicated by the No. 38 in the square) was produced on the sixtieth day and united on schedule, thirty days later, in the presence of forty-three other healing fractures. The sequence in which the fractures were produced is indicated by the encircled numbers.

nearly all the fractures without delay. There were occasional instances of delayed union in the upper shaft of the femur in fractures in which there was wide lateral displacement of the bone ends. (Fig. 8.) The animals with the multiple fractures showed, in general, a slightly higher (1.0 mg. per cent) level of the serum phosphorus but no appreciable difference in the serum calcium. Per cent ash determinations of the five vertebrae of the lumbar spines were compared in the extensively injured rats and normal controls in order to determine whether bone was resorbed or bone mineral mobilized from uninjured parts of the skeleton. No significant difference was found in the dry weight, ash weight or per cent ash of normal rats compared with animals which were healing forty-four fractures within ninety days.

TABLE I
FORTY-FOUR FRACTURES HEALING IN SERIES (GROUP IV)

Average for Seventeen Animals	Experimentals	Controls*
Healing time humerus united	20 da.	20 da.
Healing time radius united	40 da.	40 da.
Healing time ulna united	30 da.	30 da.
Healing time femur united	30 da.	30 da.
Healing time tibia united	25 da.	25 da.
Serum calcium	9.71 mg.%	10.80 mg.%
Serum phosphorus	6.20 mg.%	5.19 mg.%
Ash, lumbar spines	49.90 mg.%	46.50 mg.%

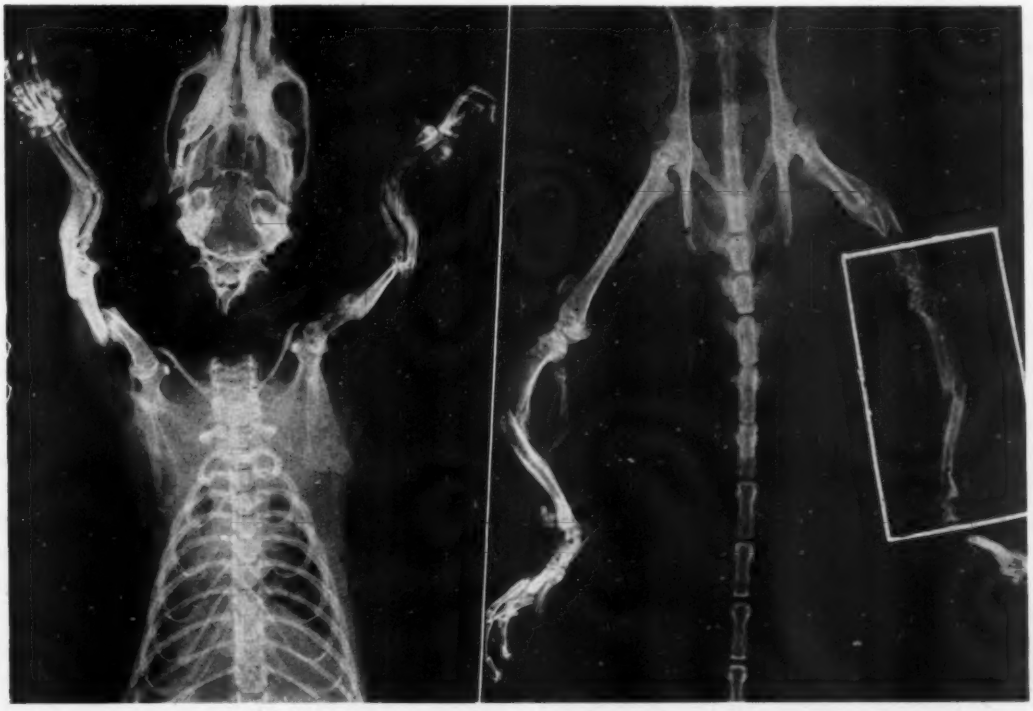
* Includes *Groups I, III and VI.*

Multiple Serial Healing Fractures in Adult Rats (Group V). Mature rats were given the same treatment as the young animals previously described. In three of the twenty-two rats nasal hemorrhages and diarrhea developed and they lost approximately one-fourth of the body weight at the fifth week of the experiment and were sacrificed for autopsy examinations. Nineteen others, with which the experiment was continued, showed normal fracture healing. The appearance of subperiosteal new bone, the subsequent growth of the spindle of callus, and the uniting of the fracture usually occurred from five to ten days later than in the similarly treated young growing rats.

Repeated Trauma to the Growing Callus in Rats with Multiple Fractures (Group VI). Sixteen fractures were produced in the long bones of the lower extremity at one operation. At five-day intervals thereafter the callus was refractured to interrupt union and, if possible, retard healing. The experiment was terminated after each callus was subjected to

9A 9B

FIG. 9. Roentgenogram of a littermate of the rat shown in Figure 8 with more than forty-four fractures produced in series at five-day intervals. The test fracture of the left tibia was produced on the sixtieth day of the experiment and was again the thirty-eighth in sequence. In this case all the fractures produced before and afterward, and the test fracture, united within the normal time schedule for single fractures of each bone.



10A 10B

FIG. 10. Roentgenogram of a littermate of the animals shown in Figures 8 and 9 shows the variation, type and completeness of healing of these fractures which were produced by manual osteoclasis. The test fracture and all the other fractures united without any immobilization in the normal period of time.

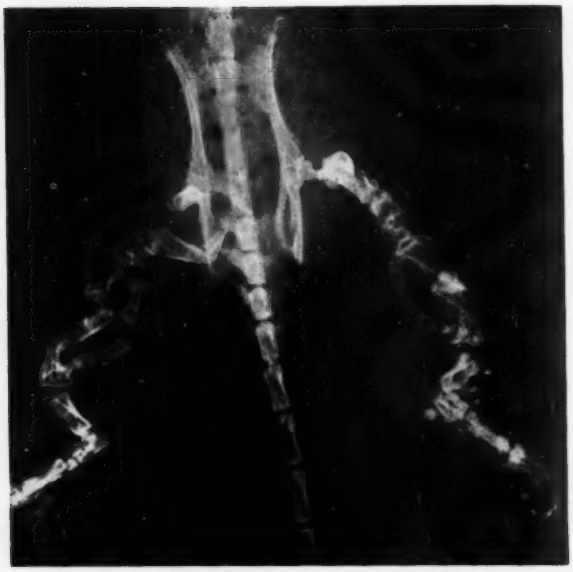


FIG. 11. Hind legs of a young rat showing fractures of the femur, tibia and fibula, and all the metatarsals. The bones were refractured every five days by manual osteoclasis at twelve successive operations in a period of sixty days and examined by x-ray ten days later. An established pseudoarthrosis was formed at every location except in the distal left femur which remained in good alignment and for some unknown reason proceeded to unite after cessation of further interference.

twelve superimposed injuries and the fracture had been permitted to heal undisturbed for ten days. The volume of the fibrocartilaginous callus was enormously increased by this treatment. It was surprising to find that in one instance the fracture united. Nearly all of the bones showed a typical pseudarthrosis in one or several places. (Figs. 9 to 11.)

COMMENTS

Systemic Reactions of the Animal to Multiple Fractures. The constitutional reactions of the animal to injury seem to be an integral and essential part of the process of repair of wounds and healing of fractures. Rats with multiple fractures present a particularly striking exhibition of the systemic reactions to trauma. Although the mortality of the operation in producing twenty-two closed fractures was negligible, approximately 50 per cent of the rats died due to delayed effects of the extensive injuries some time between four and eleven days postoperatively. In the subsequent four weeks there was severe weight loss but no further fatalities throughout the ninety-day period of the experiment. Similar animals were able to tolerate forty-four fractures without a fatality (twice the number possible at a single operation), when the fractures were produced at five-day intervals. The early postoperative weight loss was much less severe when the fractures were produced in series, but at the end of a ninety-day period the animals were also uniformly underweight. There are a wide variety and a great number of different physiologic reactions associated with shock, exhaustion and survival following extensive trauma which have been measured in metabolic studies in recent years. For a complete discussion of these phenomena the reader is referred to Seyle's Outline of the Theory of the Alarm Reaction and General Adaptation Syndrome.[18]

Metabolic studies by Cuthbertson and co-workers[5,6] show that a marked increase in nitrogen, phosphorus and sulfur excretion occurs in rats with only one or two fractures, decidedly less trauma than described here. The total measurable changes in blood and urinary electrolytes were termed the "Post-Shock Metabolic Response." The origin of this was found to be systemic, almost entirely due to the catabolism of muscle, a metabolic reaction of the organism to any severe injury and was not specific for fractures. Similar studies by Howard and his co-workers,[9–11] Bennett, Applegarth and Li,[3] and Munro and Chalmers[13] on experimental and clinical fractures clearly substantiate Cuthbertson's hypothesis that "the necessity for reparation is urgent, that the body requires rapid protein breakdown and prefers to catabolize its reserves to meet the exigencies of the moment."[6] The more severe the injury the greater the catabolism.[6] Phosphorus, nitrogen and sulfur were excreted in the same proportions as these elements exist in muscle tissue. It is probable that breakdown of muscle liberates all the materials necessary for building the organic parts of bone tissue.

Bone Regeneration. Multiple fractures have received little if any attention in experimental research dealing with the physiology of bone repair. Clinical textbooks present the thesis that patients with multiple fractures show delay in healing of one or another of the bones.[19] The late Willis Campbell wrote that, "Just how the number of fractures affects union is speculative, although the explanation may be that nature is unable to meet the demands of new bone formation."[4] A test of

Campbell's hypothesis in the aforementioned experiments demonstrates with reasonable certainty that suppression of the process of new bone formation did not occur under increased demands for bone by multiple healing fractures in either young growing rats or adult fully grown animals. In both young and old animals with twenty-two fractures produced by repeated operations, there was normal callus formation and each fracture united within the normal time.

These results are not surprising and are easily reconcilable with many of the established observations upon the physiology of fracture healing under a wide variety of circumstances. The facts are available in monographs covering hundreds of reports on fracture healing in health and disease by Bell,[2] Starr[20] and many others. There was no significant effect upon the process of callus formation and bone healing in starvation; in general nutritional, mineral or vitamin deficiencies; in any of the endocrine insufficiencies or with any other known constitutional factor essential for life or growth. A specific humoral substance which induces new bone formation, theoretically essential for callus formation, has not yet been demonstrated. Any animal which is alive, existing under the most extreme deprivation of any one of the known metabolic substances, was capable of sustaining the reparative process. The fracture site apparently holds the highest priority on tissue-building materials.

Bone Salt. Roche[17] has postulated "physiological unity to the skeleton" or synchronism between the flat bones, the uninjured parts and the long bones of the injured extremity. In rabbits or pigeons with one or two fractures Roche and Morgue[15] reported that the opposite femur and the skull were demineralized on the twentieth day after the fracture. Dallamagne[8] repeated these experiments but found "only occasional and irregular variations" in mineral content of the uninjured bones. Ash determinations of the lumbar spine in the aforementioned experiments in animals which were healing forty-four fractures showed no difference in the mineral content compared with normal littermates with one fracture. Evidently the diet contains sufficient calcium and phosphorus to calcify the new bone and accomplish functional union of the fracture. Mobilization of bone salt from uninjured parts of the skeleton did not occur to any significant degree. Local transfer of bone salt from callus-enclosed cortex to new bone, however, has been described and probably is a supplementary source of calcium and phosphorus used in fracture healing.[23] Experiments with rats on calcium and phosphorus deficient diets compared with normal diets indicate that mineral supplements are not necessary for bone repair except in rapidly growing rats in the most extreme deprivation of Vitamin D and phosphorus in the face of florid rickets all over the body.[21,22] The average normal clinical diet is more than sufficient to meet the mineral requirements of the fracture callus.[24,25]

Rate of Fracture Healing in Young and Old Animals. Only a slight quantitative difference in fracture healing was noted in immature compared with old rats. Fractures of the midshaft of the long bones healed readily in aged rats though immature rats frequently showed a larger volume of callus and often united earlier than the adults with corresponding fractures. It was frequently noted that wide displacement or overriding of the bone ends was rapidly bridged by callus in the young but not always in the aged. The most important observation was that the multiplicity of the fractures did not suppress the rate of callus formation in any one fracture even in an aged rat.

Repeated Fractures of the Callus. Fractures of the callus interfered with the processes of bridging of the bone ends. The volume of callus was greatly increased and grew larger with each fracture. In a few instances the fracture eventually united after the experiment was discontinued. In other instances the fracture was not united two months after the last fracture of the callus. In one fracture of the upper tibia the bone appeared to have united within the five-day interval between fractures of the callus. None of these experimental fractures can be considered analagous to the non-union which is seen in clinical cases.

Experimental Non-union. Retardation of both callus formation and fracture union was observed in the upper femur of animals with double fractures of the shaft of the long bones. The distal fracture line of the tibia and the proximal fracture line of the femur consistently united later than the proximal fracture line of the tibia or the distal fracture line of the femur. The proximal fracture of the femur,

particularly when displaced, failed to develop an appreciable deposit of periosteal new bone in the callus. A possible explanation is in destruction of the blood supply. The anatomic direction of the course of the nutrient artery of the long bones very likely determines pattern of healing and the sequence of union at the different locations. In the femur the major branches pass through the medulla in a proximal direction and in the tibia in a distal direction. The isolation of the central segment of the shaft and severance of a major portion of the blood supply possibly interfered with the initiation of the reparative process in these bones. Except in surgical interposition of fascia or large flaps of muscle, non-union seems not to have been described in experimental animals. The frequent finding of failure of "bridging callus formation" in the displaced upper femur appeared to be related to local circumstances. The formation of the fibrocartilaginous tissue between the cortical ends, the organization of the callus and the growth of a bridge of new bone, is obstructed when the main fragments are displaced into separate fascial planes and constricted by muscle.

CONCLUSIONS

1. Experimental multiple fractures produced concurrently, or in serial operations at short intervals, healed in the same period of time as single fractures in both young and old rats.

2. A normal diet provided enough calcium and phosphorus to sustain calcification of the callus and to develop solid union of the bones of animals with twenty-two simultaneous fractures or forty-four serial fractures in either immature or adult rats. Bone salt was not mobilized from the spine or uninjured parts of the skeleton. The serum phosphorus, however, was slightly elevated ten days following a fracture.

3. Delayed or non-union was observed only in association with regional factors. In double fractures of the shaft of the long bones, there was frequently delay in union. A consistent reaction, possibly based on the direction of the damaged nutrient vessels, was observed in the tibia and femur. In the tibia the proximal fracture line united in the normal period of time and the distal fracture always united later. In the femur the distal fracture line united on the normal schedule and there was frequently delayed or non-union in the proximal fracture line. Non-union was often noted in the upper femur when the bone ends were displaced into separate muscle compartments. Non-union was also produced experimentally by repeated fractures of the callus, probably due to interference with the organization of the callus.

4. The apparent inexhaustible capacity of the body to heal fractures (except when the aforementioned local conditions are present which lead to non-union) may be related to systemic breakdown of muscle protein which liberated the building materials needed for construction of new bone.

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USES OF REFRIGERATED BONE ON A LARGE FRACTURE SERVICE

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HOMOGENOUS bone grafts from one person to another have been utilized many times in the past with varying degrees of success. They have been most useful in cases in which a large bone graft was needed in a patient too frail to spare bone or to survive two extensive operations. Until recently there has been no satisfactory method for preserving bone grafts outside the human body; hence, homogenous bone could be used only when it was transferred directly from one patient to another.

Inclan[5] of Havana in 1939 first reported his experiences with bone grafts which had been preserved in citrated blood in an ordinary refrigerator. Two years later he described fifty-two cases in which refrigerated bone grafts had been used with 75 per cent good results.

Bush[1] in 1947 described a bone bank which had been developed at the New York Orthopedic Hospital in which bone was stored in sterile jars in a deep freezer. It was used on sixty-seven patients with excellent results in all but four patients. The following year Bush and Garber[2] reported further experience with refrigerated bone grafts and concluded that bone can be preserved indefinitely in the deep freeze and still be expected to heal satisfactorily when transplanted into the body.

Wilson[11] in 1947 reported his experiences with the bone bank at the Hospital for Special Surgery in New York. Grafts were preserved in a deep freezer and were used in thirty operations. In the filling of defects and cavities in the bones a homogenous graft seemed to heal as well as fresh autogenous bone grafts.

DeBruyn[4] in 1947 placed homoplastic and autoplastic transplants of bone, bone marrow and periosteum, fresh and devitalized by freezing in liquid nitrogen or dry ice, in the thigh musculature of rabbits. He found that freezing seemed to destroy the bone cells and bone-forming substances.

Speed and Smith[9] in 1949 stated, "The use of refrigerated homogenous graft now offers a practical solution to many difficult reconstruction problems."

Robert Mark Kimball[7] in September, 1949, presented his experimental study on the use of bank bone to the San Diego, California, Orthopaedic Club. Homogenous and heterogenous transfers were done with fresh, frozen and boiled bone to the anterior chamber of guinea pigs' eyes. He demonstrated survival of transplanted homogenous bone and the initiation of osteogenesis by heterogenous bone. He further demonstrated that fresh bone and bone frozen up to nine days had about the same ability to initiate osteogenesis whether homogenous or heterogenous. It was his opinion that freezing simply prevented the death and disintegration of the cells for variable periods so that these cells were able to retain their bone-forming substance until transferred.

Weaver[10] in October, 1949, reported a series of forty-six cases in which refrigerated bank bone was used. He used fresh cadavera bone in seventeen of the cases and thought it to be just as efficient as that taken from patients.

Coley and Higinbotham[3] in November, 1949, reported sixteen cases in which ribs stored in a refrigerated bone bank were used to fill cavities following the removal of tumors, cysts, fibrous dysplasia and eosinophilic granuloma.

Dr. Philip Wilson visited Brooke General Hospital, Fort Sam Houston, Texas, in September, 1947, and pointed out the great value of having a bone bank for the use on the Orthopedic Service. The necessary equipment was secured and in January, 1948, the collection of bone grafts for the bank was begun. Since February, 1948, bone grafts from the bone bank have been used in sixty cases for the filling of defects, bridging ununited fractures, arthrodesing of joints and supplementing the open

reduction and internal fixation of fresh fractures.

There were 106 grafts obtained from twenty-eight donors who varied in age from eighteen to seventy-eight years. Grafts were obtained from the ilium (when excess bone was removed during autogenous grafting) and from the femur, patella, tibia and tarsal bones (in cases of amputation at the thigh). Thus cortical and cancellous grafts were available. There were forty grafts discarded because of history of infectious diseases, syphilis and contamination.

When bone was removed from the donor patient, it was immediately cut into suitable sizes and placed in a sterile glass jar. A small fragment was taken from each graft and sent to the bacteriology laboratory for culture in thioglycolate broth. It was further cultured, if indicated, on agar plates for the usual contaminating organisms. The sterile glass jar containing the bone graft was placed within another larger sterile glass jar and sealed with a screw cap. This jar was placed in a segregated compartment in a deep freezer, maintained at −12°C., in which it was kept until bacteriologic studies were completed.

To each jar was an attached tag which tabulated the date the bone was taken, the name of the donor and the fact that there was no history of syphilis, malaria, infectious hepatitis, serum jaundice or recent infection. When the bacteriologic report was available ninety-six hours later, any grafts showing positive cultures were removed from the deep freezer and discarded. Those grafts showing no evidence of cultural growth of bacteria at the end of ninety-six hours were transferred from the segregated compartment of the deep freezer into the general storage compartment in which they remained until they were needed for subsequent bone graft operations.

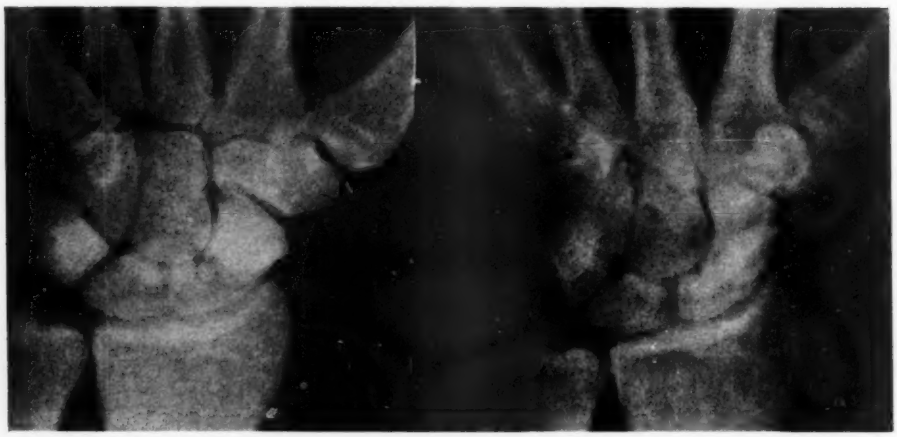
When bone grafts were needed from the bone bank, the grafts were selected for size and type the night before the operation and the jar placed in a refrigerator to begin the thawing process. About two hours before the time of the operation the jar containing the bone was removed from the refrigerator and allowed to thaw at room temperature. During the operation the outer jar was opened with sterile precautions and the inner sterile jar was lifted out and placed on the instrument table. The jar was opened when the bone was needed and the grafts prepared for immediate use. The bone was always found to be moist and normal in appearance and texture and could be used in the operation exactly like autogenous bone.

FIG. 1. A, non-union of a fractured clavicle which was grafted seven months after injury. B, two months after an intramedullary Kirschner wire and bone bank graft were applied. C, results four months postoperatively.

If, for any reason, the grafts from the bone bank were not used in the operation or if a major portion of the bone was unused, it was replaced in a fresh sterile jar, cultured in the same way as fresh bone and returned to the deep freezer. Grafts were thus saved for future use and some were replaced in the freezer as often as five times before they were placed in the final host.

Bone grafts were kept in the deep freezer for periods ranging up to 198 days. In the sixty cases reported, sixty-six grafts of bone were used which had been preserved in the deep freeze for variable periods prior to use. (Table 1.)

The sixty cases in which homogenous bone was used covered a wider variety of conditions



2A 2B

FIG. 2. A, non-union of carpal navicular bone which was grafted with bank bone three and a half years after original injury. B, results three months postoperatively.

than has been reported in any previous experience with bone from the bone bank. (Table II.)

There were only four failures (6.6 per cent). One bone graft to the clavicle failed to unite, one grafting operation to the radius resulted in non-union, one arthrodesis of the knee failed to fuse and one case of transplanting bone into an osteomyelitic area for non-union of the tibia continued to drain. All of these four patients had original compound fractures with resulting infections, and it is probable that any graft either autogenous or homogenous would have failed. In all of the others (fifty-six patients) there was clinical and x-ray evidence of solid bony union with complete incorporation of the bone grafts into the host bone. (Figs. 1 to 8.)

These patients, in addition to having a great variety of pathologic conditions, were also widely separated in age groups. (Table III.)

Kiehn, Friedell and MacIntyre,[6] with the aid of radioactive isotope tracers, found that refrigerated bone transplants remained dormant for four weeks after which they healed as rapidly as the usual vital grafts. This suggestion that homogenous bone grafts might be a month slower in healing than autogenous grafts caused us to determine by roentgenologic and

TABLE I

PRESERVATION PERIODS OF BONE GRAFTS PRIOR TO USE

Weeks	No. of Cases
1	11
2	14
3	6
4	7
5	3
6	2
7	1
8	4
10	5
11	2
12	2
13	2
15	3
16	1
20	1
25	1
27	1

TABLE II

TYPES OF BONE GRAFT OPERATIONS

Operations	No. of Cases	Total
Repair of ununited fractures	..	33
Shaft of tibia	12	..
Shaft of humerus	1	..
Bones of forearm	8	..
Bones of hands	5	..
Shaft of femur	2	..
Clavicle	2	..
Mandible	3	..
Arthrodesis of joints	..	13
Spinal fusion	8	..
Knee fusion	3	..
Shoulder fusion	2	..
Repair of fresh fractures	..	12
Palmer operation of os calcis	5	..
Internal fixation and graft of femur	5	..
Rush pin and graft of humerus	1	..
Kirschner wire and graft of radius and ulna	1	..
Filling bone defects	..	2
Tumor cavity	1	..
Osteomyelitic cavity	1	..
Total	..	60

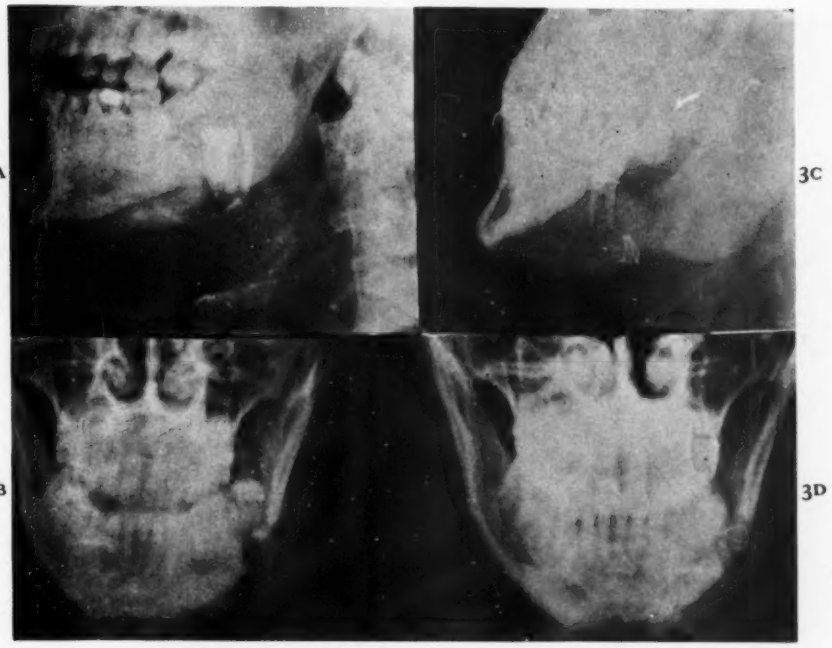


FIG. 3. A and B, non-union of the body of the mandible which was grafted with bank bone three months after original injury. C and D, results five and a half months after fixation of iliac graft with wire.

FIG. 4. A, non-union of multiple comminuted fractures of the tibia and fibula which were grafted fourteen months after injury. B, bank bone graft incorporating two months postoperatively. C, results five months postoperatively.

5A 5B 5C

FIG. 5. A, non-union of the fourth metacarpal bone for which an intramedullary bank bone peg was applied two months after initial injury. B, intramedullary bone peg and Kirschner wire fixation maintain reduction. C, results five months postoperatively.

6A 6B

FIG. 6. A, delayed union of subtrochanteric fracture of the femur following a gunshot wound for which an iliac bank bone graft and a Jewett nail were applied three months after injury. B, results five months postoperatively.

clinical examinations the time interval of healing in the grafts we performed. We discovered that solid bony union occurred in fifty-three cases within six months following the application of refrigerated bone grafts. (Table IV.)

TABLE III

AGE GROUPS OF RECIPIENTS

Decade	No. of Cases
2	11
3	28
4	8
5	6
6	3
7	4

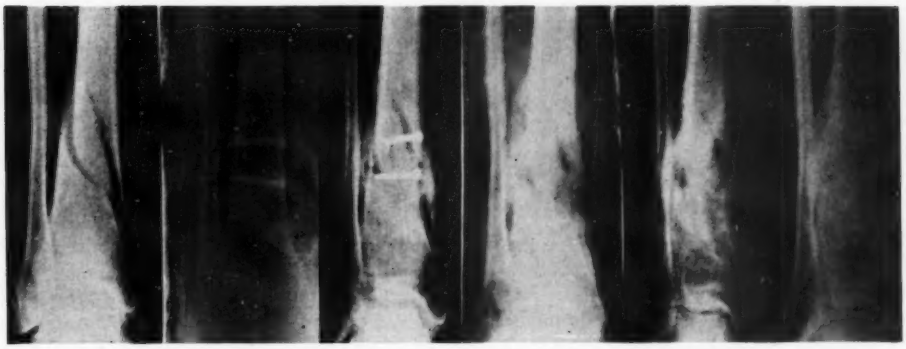
TABLE IV

TIME INTERVAL OF HEALING

No. of Cases	Months
10	3
18	4
13	5
12	6
3	7

CONCLUSIONS

Massive cortical grafts of homogenous refrigerated bone are suited mainly for spinal fusions.



7A 7B 7C 7D 7E 7F

FIG. 7. A, simple fracture of tibia. B, screw fixation two weeks after injury. C, four months postoperatively and presence of osteomyelitis. D, two weeks after the removal of the screws. E, osteomyelitic area was curetted and filled with bank bone chips nine months following injury. F, results thirteen months after application of bank bone graft.

8A 8B

FIG. 8. A, enchondroma of the index finger with pathologic fracture. B, results one month after the tumor had been excised and the cavity filled with bank bone chips.

For ununited fractures, homogenous grafts are best used as thin slices of cortical bone placed as barrel stave grafts about the host bone.

Cancellous bone from the bone bank is useful to fill spaces about an ununited fracture, to supplement cortical grafts and to fill hollow bone defects.

Homogenous refrigerated bone has many uses in orthopedic surgery as we have demonstrated in these sixty cases. The likelihood of success is higher than has been previously supposed.

In an editorial, Lipscomb[8] stated, "We do not have evidence as yet in a large series of comparable cases that the percentage of 'takes' of frozen homogenous transplants is as high as that of fresh autogenous bone." A partial answer is this comparatively small group of sixty cases which has been attended by 93.4 per cent successful healing of frozen homogenous bone.

The advantages of easily accessible, previously prepared bone grafts are so obvious that it seems we must continue to use the bone bank in ever-increasing situations in which supplementary bone is needed.

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DISCUSSION OF PAPERS BY DRS. HUDACK AND BLUNT, URIST AND MCLEAN, AND STUCK AND DANDRIDGE

Frederic W. Bancroft (New York, N.Y.): Dr. Hudack's paper is extremely interesting, although at the present moment it does not seem to have a practical application in our handling of patients with fractures. However, his study of early granulation tissue in the repair of fractures is getting us back in a scientific way to the formation of fibrin and granulation tissue, which must eventually solve our problem.

We have gotten away from the osteoblastic theory, that it is a cell that secretes bone, and we have arrived at the theory that granulation tissue does form bone and will form bone in any part of the body, assuming that the biochemical factors are favorable. Fascia lata transplants can be placed in the bladder and true bone will be formed. One finds bone in the adventitia of the artery but never in a similar position in veins. I think we must arrive at some biochemical basis as to osteogenesis.

As far as Dr. Urist's paper goes, I should like to ask him if he has taken the bone ash of the bones in the immediate vicinity of the fractures. In my early studies of bone repair it seemed to me that the bone cells died in the immediate vicinity of the fracture. There would be atrophy and little bone cysts and it seemed to me that probably the calcium and phosphorus for the osteogenic tissue originated in the immediate vicinity of the fracture and not from the blood stream. I think that his multiple fractures seemed to show that.

When we come down to bone banks, I think the problem that has stumped us all is the matrix of bone. It is obviously a tissue of low metabolic range. I have removed from a knee joint a foreign body that had no vascular connection by any pedicle with the enveloping synovial membrane. This foreign body had cartilage cells and bone cells on the exterior and a calcified matrix in the center. It was nourished by the synovial fluid and not through any vascular connection with the host. Also, during my early experimental work on bone transplants, taking small fragments of 2 to 3 mm. and placing them in the bone defect after having removed the periosteum and endosteum, I found the following facts: All of those fragments would lose their nuclei in a very short time, within a week, so that I had living matrix without living bone cells in it. As repair went on, I could see revascularization through the old Haversian canals and then active bone cells where it was revascularized but no active cells where the circulation had not been reestablished.

I think that is the reason we have failures in a good many of our bone transplants. We do not get circulation if we put them in scar tissue and we do not get revascularization. I think "creeping replacement" is a very good term for this. The matrix persists but the cells disappear and then are brought in again through circulation.

I believe one factor that has hindered our conception of bone is that we studied the skeleton as an inanimate, calcified structure and we got the idea that it remained that way. It does not. If a tooth is removed, the jaw changes. If one has a wry neck, the skull changes shape. Bone is a constantly changing organic substance with a low metabolic rate.

Harrison L. McLaughlin (New York, N.Y.): Dr. Urist has added one more nail to the coffin of a specific osteogenic humeral substance by demonstrating that in comparable animals twenty-two fractures heal as rapidly and as well as one. He has

reiterated the fact that diet is not a factor in bone healing and, in view of this, his conclusion that a normal diet is sufficient to sustain healing is surprising. Does he infer that a subnormal diet would not sustain healing?

He remarks upon the specific osteogenic properties of periosteum. I have practiced and taught for many years that in the course of open reductions all periosteum separated from its soft part attachments be excised. Sometimes a considerable amount requires removal lest it remain as a devitalized barrier to revascularization of the bone. In clinical practice excision of periosteum does not impede union. Fastidious surgical grooming of the fracture region, hemostasis, anatomic reduction and rigid fixation of a fracture normally result in what might be termed bone healing per primam, regardless of the status of the periosteum. The absence of these factors normally results in what might be called union by secondary intent with a large mass of circumferential reparative tissue, which we applaud as laudable callus, but which seems comparable to the proliferation of a mass of scar tissue at a poorly healed soft part wound.

A. M. Okelberry (Salt Lake City, Utah): We have done some thirty-odd cases in which we have used bank bone. We have had excellent results, having had only one infection and hardly any way to explain that one. The case was one of a defect in the lower third of the tibia from a compound fracture that had required grafting and so on, but in that case, there was a staphylococcus infection. Probably we will lose those grafts.

We have used bank bone in quite a variety of procedures, more spinal fusions than anything else, however. Six cases of non-union of the tibia are included in this group. In the first case the operation was done about two years ago, and we used some badly fragmented patellar bone that had been removed from a fractured patella. This was inserted beneath a depressed fracture of the lateral plateau of a tibia. The final result in that case has been much better than we expected, being very satisfactory from a clinical standpoint.

We have had two cases of fibrous dysplasia of bone, one of the humerus and one of the fibula in which bone from the bank has been used.

An interesting observation is that we have not had any patients who objected to the use of bank bone. They have taken the idea rather lightly, I guess being schooled in the use of bank blood. They have not objected. We did have one girl who specified what type of bone she wanted. She wanted rib, and at first she thought she would like it from a man and then she changed her mind and decided she would rather have a lady's rib bone. We were able to accommodate her because we have a fair number of rib specimens that Dr. Vincent Rees, who is one of my associates, saves from rib resections in doing sympathectomies.

Incidentally, rib bone seems quite ideal for laminectomy defects. We have had one case recently in which two laminas in the cervical spine were removed and then the bridging was done with rib grafts. From the x-ray check-up at the end of ten weeks, it would appear that everything is progressing satisfactorily.

We have not taken routine cultures of bone removed. Perhaps we should have done that.

I should like to ask some questions of Dr. Dandridge, namely, what is the risk of contamination of this bone that we may save from operative procedures? In other words, in how many cases in their series has contamination of the specimen occurred?

Also, have any of their cases been open wounds at the time of grafting? I know that Dr. Wilson reported one and Dr. Dandridge at least intimated, by saying that the wound continued to drain, that perhaps this one case of osteomyelitis had not been completely closed.

One disturbing thing in some of the specimens that we have used recently, obtained from an amputation of the lower end of the femur including the condyles, is that this bone, after being preserved for a couple of months, seems to be quite oily at the time we divide it into small chips. I have wondered if that oil, which we are not able to express out with a sponge, will have any actual interfering effect in the formation of new bone.

Ronald Adams (Boston, Mass.): I thought it might be of interest to report on another use of bank bone which we at Boston City Hospital have used—whether for good or for ill, I am not yet prepared to say.

We have had a bank in operation since 1947, and at the present time, have treated approximately 160 patients with bank bone. In looking around for more indications for its use, of course, we have been troubled with the delay and non-union in cases of compound fracture. I think it was approximately nine or ten years ago that the late well remembered Claywell Murray, before this very group, gave a paper on the immediate internal fixation in compound fractures. It was controversial at that time, but today there is probably hardly a surgeon here who has not used it. Therefore, last September we started with this program and have employed it in six cases, fresh cases of compound fracture, in wounds in which we thought internal fixation could be used.

Of course, this is a preliminary report. We certainly do not have enough cases and not long enough follow-up to give you a final report on it, but it may be stimulating to some of you who have bone banks at home.

STEPHEN S. HUDACK (closing): For many years now at the Presbyterian Hospital we have had an instinctive feeling that the general metabolism of the patient and his well-being have, perhaps, something to do with how he responds to care. With all humility I have in my paper tried to give you some of the highlights of the work that we have been doing in trying to see what are some of the basic processes that go on in repair.

I do not make any apologies for those things that I have said, because I believe that this organization concerned as it is a great deal with the surgery of the motor skeletal system, must be overscrupulous in considering the basic physiologic processes that go on and consider the patient as a whole, and not look at their problems as simple mechanical ones.

My comment upon Dr. Urist's paper is that it just shows you that minds run along the same channels, implicating the general response in the cortical steroids, in the alarm reaction for the adaptation of the animal organism to trauma. I hesitate very much to try to make any clinical correlations from the things that Dr. Urist observed, except that he has redocumented in part, the extremely important and sometimes very profound physiologic changes that go on in the body economy as a result of trauma.

CHARLES S. VENABLE (San Antonio, Tex.): I think progress is definitely being made in observation and in clinical observation, particularly now with the bone banks, whether you freeze the bones, boil them or paint merthiolate on them.

I have always been impressed by the fact that an autogenous graft was preferably the graft to use; and if that autogenous graft was going to take and did take, as we understand the take, it picked up nourishment from the plasma and other tissues and fluids of the body as well as the blood supply, and continued by x-ray review to look something like the parent bones at both ends of where it was. I will not go any further than that; it is just an observation. When the grafts did not look that way and died I believe there were many opportunities in which they followed through with a trellis.

I want to take this opportunity to tell you of a recent and most interesting observation made just a short time ago. A man had both bones of the forearm broken some four or five months before. There had been no infection, but the bones had been badly set and his hand was twisted around so he would have to eat his soup backward. It meant undoing this malposition with non-union to the extent that part of the ulnar was engaged to the lower end of the radius. After dissection I undertook in two stages to put in autogenous bone graft from the crest of the ilium. In the graft between the ends of the ulnar there was a space about 2 inches or more. I did that first and froze it in place, and held it in position with a plate. About a week or ten days later I undertook to put a graft into the radial site. The graft I put in the radial site had been put in the deep freeze and came out of a bank. That was also autogenous bone from the same patient. I put this graft between the radial ends and also held it in position with a plate and plaster in the usual way.

At the end of a six-week period the cast was removed for x-ray purposes, and the graft between the ulnar fragments was as large as active living bone, with early union between the bone ends. The graft between the radial ends was not more than 60 per cent of the density of the living graft between the ulnar fragments.

There was at each end of that graft, between that and the distal and proximal ends of the radius, a space that could be seen definitely through the x-ray about the width of a thumbnail. The extremity was replaced in the plaster, of course, and then it was reviewed again very recently at the twelve week period. The cast was taken off, the bone growths in the ulnar are a perfectly firm union and I would let the man go about his business.

The density between the radial ends had decreased to possibly 20 or 25 per cent. It is in exactly the same position. But the interesting thing is that although it is now homogenous, the transmitted light between each end of the radius and each end of the graft is filled with a shadow of this autogenous bone, if you choose to call it that. I think it a very interesting thing to take an autogenous graft out of the same man at the same time, with the same blood supply, the same fixation and the same everything else, and watch the fade-away of the bone that was frozen and the growth and fixation of the bone that was not frozen.

MARSHALL R. URIST (closing): We have presented an experimental study which deals with the essential process of bone repair. The process of callus formation is probably the same in all animals from fish to man.

Questions about systemic treatment of clinical fractures can be investigated profitably by such experimental researches on animals. The results of this report show that if there is any justification at all for medical treatment of a patient with multiple healing fractures, it would be to feed a high protein diet, preferably in the form of meat. This should replace the substances lost in the breakdown of stored protein of the body muscle.

The modern beginning of the local factor hypothesized by Bancroft, Murray and Hudack in fracture healing began with the writings of Leriche and the work of Policard. Bancroft and Murray championed a local mechanism as the specific factor of bone formation in fracture healing and postulated the osteogenic action of the local

changes in pH in the fracture site, particularly in the fractured hematoma. The main evidence against this theory is that no appreciable change in the pH of the fracture site has been demonstrated, and no one has ever found appreciable absorption, dissolution, chemical dissolving, of the bone ends in the fracture site. As a matter of fact, there is usually an increase in density of the bone ends due to appositional bone formation. We have not done bone ash determinations on the bone ends.

Murray went as far as to say that the fracture site was a closed chemical factory. It is difficult for us to understand how the growing callus can constitute a closed chemical factory.

Dr. Hudack's report today was most interesting. Experimental work on action of cortisone on wound healing and the early process of healing fractures should add a great deal to our knowledge of bone repair. Dr. Hudack showed that cortisone inhibits the formation of fibrous tissue. Cortisone is an antianabolic; it inhibits the construction of certain tissue proteins.

The main difference of opinion between Dr. Hudack and myself is in the "theory of the closed chemical factory." We believe there is plenty of outside supply of labor and materials in healing fractures. The main source of labor is osteoblasts, and the main source of material comes from degeneration products of muscle tissue.

Dr. McLaughlin raised the question about the difference in the gross appearance of the healing of a fracture of the tibia treated with open operation. There is no evidence for or against the "local chemical theory" of fracture healing. I think the fracture of the tibia reduced anatomically as tightly as possible and fixed with plate does show callus formation. It shows much less callus formation than unopened fractures for the following reasons:

In cross section the tibia is a triangle. On the lateral side is the muscle and on the medial side is skin and periosteum which is very avascular. On the posterior side is also muscle but very good blood supply. In the treatment advocated by the Fracture Service at the Presbyterian Hospital, a bone plate is laid into the lateral side of the leg and this almost completely inactivates the lateral side of the tibia. Very little happens on the medial side of the tibia in the healing fracture of the lower and middle third, and almost all of the external callus formation is on the posterior side. One needs only to examine the lateral view of the tibia to see the callus growing on the posterior side of the tibia. In the case of a fracture of the femur, treated with an open operation, there is always some external callus formation whether treated with open or closed methods.

In 1944 Dr. Stuck told me that he thought the value of the bone bank will be determined in the end results of the various operations with the use of homogenous bone. This survey of the individual cases treated by Stuck and Dandridge shows that refrigerated bone grafts are fully as good as autogenous grafts. Probably the best test of a bone graft or the action of a bone graft is in an operation for ununited fracture of the lower third of the tibia. Stuck and Dandridge report twelve such cases. There was only one failure and that was due to recurrence of old sepsis. A point well taken by Stuck and Dandridge is that the treatment of the graft is a critical factor in the operation. The massive graft which is good in a spinal fusion is not as good as thin strips of bone for filling defects.

Although bone banks have been established in many of the major medical centers throughout the nation, preserved bone is still not in universal use. The majority of bone surgeons are still making a second incision and are using autogenous bone for nearly every operation. There are several reasons for this situation, namely, (1) smaller hospitals do not provide the facilities for maintaining a continuous supply of sterile bone; (2) the conscientious surgeon naturally hesitates to use bone from a source not completely controlled by him and (3) the mechanism by which a bone graft attracts the osteogenetic process and permits substitution by the host tissue is not well understood.

Reynolds and Oliver recently reported a study in which they compared fresh, frozen and merthiolate-treated homogenous bone with fresh autogenous bone. With homogenous bone there was a latent period of adaptation of the graft in the tissue bed of the host, which did not occur with autogenous bone. After the four-week latent period as seen microscopically in the host tissue reaction, the supportive or passive function of the preserved graft was fully as good as the fresh grafts. The differences in these bone grafts are in: (1) genetic compatability of the bone tissue and (2) the foreign body reaction caused by the denatured protein of the frozen or fixed tissue.

The osteogenic potency of the host tissue, however, not the graft is, therefore, the main thing in the end results of a bone graft operation. The bone graft matrix appears to contribute something more than an inert fabric in which osteoblasts proliferate and lay down the new bone, but nothing is known about the chemical processes involved in "creeping substitution."

WILLIAM S. DANDRIDGE (closing): Dr. Venable, in bringing out the fact of the fading away of the graft in the one that was frozen, has presented an experience similar to some of ours. We find that that is to some extent a common occurrence. We took microscopic biopsy sections, studied them under the microscope at different stages of healing, and found that the bone that was transplanted underwent absorption and apparent replacement

by the host tissue. That in itself explains why you have the diminished density on your roentgenograms during this phase of healing.

Dr. Okelberry asked about contaminated specimens. We discarded forty such grafts. Some of these cases had histories of conditions such as syphilis or recent infections or inadequate histories which we could not verify. Therefore, we eliminated five of the grafts from that count. The remainder of the grafts were discarded because of ordinary contaminants such as hemolytic and nonhemolytic staphylcoccus, hemolytic and nonhemolytic streptococcus, and one Pseudomonas. These are ordinary contaminants and the grafts should be as sterile as possible prior to their use. We took the precautions, after they were removed from their donor, of immediately making bacteriologic studies, in order to try to keep them as sterile as possible throughout the procedure.

He asked, also, have any of the cases been open wounds. There were three cases, all of them happened to be of the tibia; and as I have previously stated in my paper, one of them went on to a nonhealing process and continued to drain over a period of time. Recently, I was informed that this particular patient has gone ahead and healed solidly.

In the amputation of bone that he described, Dr. Okelberry said that he had observed that there was an oily solution around the graft site or around the graft prior to its use. We have found this to be true in cases in which we had previously used a portion of the graft and had placed it back in the refrigerator for deep freezing and then subsequently used it again. Those patients healed without any difficulty. However, even though the graft was somewhat oily, we did not make any attempt to extract the oil.

MILD HEAD INJURY (CONCUSSION)*

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THIS paper deals with mild head injury and the subjective symptoms that follow it in many patients. These symptoms, if persistent, cause much suffering to the patient and are responsible for much expense to industrial concerns and insurance companies because of time lost and compensation paid. In some cases awards for partial or total permanent disability are made. Much of the interest in head injuries has been rightfully focused on lowering the mortality and morbidity in severely injured patients. Consideration of the patient with mild head injury is often limited to an admonition to observe him for some complication, especially that of extradural or subdural hemorrhage. More attention to the physiologic and psychologic basis of the symptoms produced by mild head injury will be amply repaid by the prompt recovery of larger numbers of these patients.

Pathogenesis. The terminology of the pathology of brain trauma is confusing, at least as far as the literature is concerned. A great share of this confusion centers around the term "concussion" and a good many authors have suggested that it be dropped entirely. However, the term is a valuable one and should be retained, but reserved for those cases which show transient loss of consciousness with no objective evidence later of localized brain injury. Scott[21] reported some very fundamental experimental work on the physiology of concussion. He found that a blow of sufficient force to render a dog unconscious caused a momentary rise of intracranial pressure as measured with a Hamilton manometer to a height considerably above the systolic blood pressure. After the blow the pressure immediately became normal and remained so. Consciousness was never lost unless the intracranial pressure did exceed the systolic blood pressure at the time of the blow. In these cases no intracranial hemorrhage or other alteration that could be seen with the naked eye was produced. This suggests that concussion represents a short-lasting cerebral anemia. Gurdjian and Lissner[10] using cathode ray oscillography to record changes in intracranial pressure demonstrated similar rises in intracranial pressure at the time of a blow to the head. These were associated with demonstrable deformation of the skull.

Denny-Brown and Russell[3] accumulated evidence that concussion was due to direct mechanical action on the nerve cell which they considered to produce a temporary paralytic effect. They considered the loss of consciousness to be related to acceleration or deceleration of the head. On the other hand, Walker, Kolross and Case[23,24] considered concussion to represent an excitation of cortical nerve cells followed by physiologic extinction as termed by Dusser de Barenne and McCullough.[5] These authors consider that this phase of physiologic extinction represents the paralytic effect emphasized by Denny-Brown and Russell.[3] In their experiments it made no difference whether the force was applied to a moving or a fixed head.

The type of force required to produce concussion has been extensively investigated. Walker, Kolross and Case,[23,24] using a Hamilton manometer, assumed that oscillations in pressure were responsible for mass stimulation of neurons rather than momentary cerebral anemia. Denny-Brown and Russell,[3] Fulton,[8] and Munro[18] emphasized the importance of acceleration and deceleration in producing concussion or more serious injury. They considered that the human head would tolerate deceleration from a speed of 200 miles per hour in $\frac{1}{100}$ of a second without serious consequences; but if the deceleration takes place in $\frac{1}{1,000}$ of a second, serious, if not fatal injury results. Ward, Montgomery and Clark[25] postulated a mechanism of concussion. They believed that a blow to the head brought about the passage of an intense rapid pressure wave which damaged nerve tissue by producing cavitation ("formation and vehement col-

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lapse of cavities"). These cavities are small (microscopic) and irregular, thus accounting for the irregular chromatolysis reported by Windle and his co-workers.[9,28,29]

In injuries that only produce temporary cerebral anemia or temporary disturbance of function of the nerve cell, the only changes in the cerebral circulation are reversible. This type of injury produces a certain degree of shock or collapse manifested externally by a fall in blood pressure, pallor, sweating and shallow respiration. Slight convulsive movements may occur. The capillaries and arterioles are distended and the patient temporarily "bleeds" into his tissues. However, on regaining consciousness the patient rapidly recovers from all of these symptoms. In the past it has been considered that concussion resulted in no demonstrable gross or microscopic damage to the nerve cell. The studies of Groat, Windle and Magoun,[9] and Windle, Groat and Fox[28] indicate that this is not true. They observed in both the guinea pig and the monkey differential chromolytic changes in the pyramidal cells of the motor cortex and in the brain stem. These changes were unassociated with any interstitial hemorrhage, glial reaction or nerve fiber degeneration. These chromolytic changes are apparently associated with uncomplicated concussion. The less severe are progressive, cumulating in disappearance of the cell. However, the data on cell disappearance were taken from guinea pigs and monkeys who had received severe blows at spaced intervals and represent the effects of repeated, rather than a single injury. These authors, like all modern writers, emphasize the desirability of not confusing concussion with contusion or laceration of the brain or with the various post-traumatic syndromes.

White, Brooks, Goldthwait and Adams[26] found an increase in brain volume up to 5.5 per cent appearing within fifteen minutes after experimental concussion in cats, reaching a maximum in five to twenty-four hours and gradually subsiding after three days. Windle and his co-workers[29] likewise found slight but significant increase in the water content of the brain after concussion. However, experimental brain edema produced by "water-logging" animals failed to produce the characteristic cellular changes (chromatolysis) seen in experimental concussion.

Occasionally headaches, dizziness or even slight degrees of personality changes may follow concussion. This is more likely in older individuals, especially those with demonstrable pathologic changes in their arteries. Repeated, mild traumas with short periods of unconsciousness are known to produce definite permanent mental and neurologic changes—the so-called "punch drunk" syndrome. This is apparently due to the effects of repeated mild damage to the cells plus the effects of the repeated insults to the capillaries and smaller blood vessels. The degenerative changes described in the basal ganglia, corona radiata and frontal lobes by Martland[16] and others are comparable to those that may follow a single severe trauma from which the patient recovers but with permanent sequelae comparable to those of the "punch drunk" syndrome. Thus repeated concussion may give an end result comparable clinically and pathologically to that of general cerebral contusion.

Clinical Considerations. From a clinical standpoint one of the most important criteria of the initial severity of a brain injury is the duration of the initial period of unconsciousness. The history of this seems and may be easy to obtain but is often shrouded in mystery. On the one hand there is a notorious tendency of laymen to exaggerate the time that a patient is unconscious following an injury just as, for example, they notoriously exaggerate the duration of such phenomena as convulsive seizures. On the other hand a patient may be dazed and, particularly if he is so unfortunate as to have the odor of alcohol on his breath, be described by witnesses as intoxicated when in fact he has a disturbed state of consciousness from the injury. Again he may conduct himself in a rational and apparently normal fashion but later be unable to recall the accident or events occurring for several hours thereafter. Such states of automatism or amnesia are very significant. If consciousness is actually lost, the patient will be unable to recall receiving the blow or force to his head that produced unconsciousness. As Munro[18] has pointed out, this so-called "retrograde amnesia" will vary in extent with the severity of the injury.

At the time of, or shortly after a concussion, various neurologic signs such as dilation of the pupil, convulsive twitching of various muscle groups, absent or diminished superficial reflexes and pathologic reflexes such as the

Babinski and Hoffman signs and ankle clonus may be present. These objective abnormalities are fleeting in patients with concussion and do not persist. Usually they can no longer be found by the time medical attention is obtained.

The electroencephalogram (E.E.G.) is of considerable diagnostic value in determining the rate of recovery and the likelihood of sequelae.[11,12] Abnormalities occur constantly in all cases of significant brain injury although in mild cases these abnormalities are fleeting. Their severity and persistence is dependent upon the severity of the injury. Dow, Ulett and Raaf[4] made electroencephalograms on 197 cases of mild head injury and concluded that they were less reliable than clinical judgement in predicting time lost from work.

There is a syndrome or group of symptoms seen after head injury which is referred to as the post-concussive syndrome or the post-traumatic syndrome. It includes headache which may be generalized or localized, usually exacerbated by fatigue, nerve strain or attempts to work, and described as a pressure in the head or a band around the head. The headache tends to be recurrent rather than constant. Dizziness is usually present, is aggravated by postural changes and may be a predominant complaint, especially in older patients. Irritability and impulsiveness are often complained of by relatives and friends rather than by the patients. Easy fatigue, inability to concentrate, loss of memory for recent events and lack of initiative are common. These patients are often intolerant of stimuli, especially noises; they perspire readily and often excessively and may complain of tachycardia or palpitation. Also, their tolerance to heat and alcohol is diminished. Neurologic examination fails to reveal any gross abnormalities. The deep reflexes are often increased, bilateral Hoffman signs may be present, percussion tenderness (either generalized or localized) of the skull is common and the labyrinths may be hyperactive to caloric or galvanic stimulation. Encephalography often reveals slight enlargement of the ventricles and either enlargement of the subarachnoid spaces or failure of these spaces to fill properly. Unfortunately, we have no information on how often such findings occur in patients without subjective complaints. Jasper, Kershman and Elvidge[11,12] have presented evidence that the electroencephalogram may be depended on to differentiate those cases with organic cerebral damage from the purely functional cases. More evidence controlled by pathologic, operative and pneumoencephalographic studies is urgently needed.

There is considerable disagreement in the literature concerning the functional changes in the nervous system following trauma. The question of the presence or absence of organic changes in the central nervous system in these cases, the relationship of the desire for compensation and the difficulties in composing medical and legal opinion have all complicated the problem. The role that desire for financial compensation or relief from responsibility plays cannot be denied. Children as a rule are not subjected to these desires and it is well known that children do not often have persistent subjective symptoms after a mild injury. When they do show such symptoms, the parents are usually found to be oversolicitous or to exhibit a marked desire for compensation. The writer has had experience with a large series of head injuries in a large public hospital, The Cook County Hospital. These patients in many cases have had no hope of financial gain from their injury. His experience with a group of private patients, most of whom do have such hope, is radically different as far as post-traumatic symptoms are concerned. Functional sequelae are much less common and persistent in the public hospital patients. However, it must be remembered that economic position and type of activity plays an important role. The clerk or executive may be disabled by subjective complaints, such as loss of memory and inability to concentrate, which would be bearable or even unnoticed in a laborer.

McKenzie[17] and Siris[22] believed that the pathogenesis of the post-traumatic syndrome was an injured and unstable cerebral vasomotor system. In order to promote the early restabilization of cerebral vascular tone they urged early ambulation of patients with mild head injury.

Denny-Brown and his associates[1,2,6] emphasize the importance of both the physical and psychogenic factors in the production of the post-traumatic syndrome. They studied 200 patients with head injury and reached the conclusion that the persistence of headache and dizziness for more than two months after a mild head

injury was always associated with psychogenic factors.

Schaller[20] placed midway between the sequelae due to organic structural changes in the brain and the purely psychogenic states a group of syndromes variously designated as traumatic encephalopathy, traumatic head syndrome, punch drunk or concussion neurosis, and referred to them as the post-traumatic concussion state. The syndrome of "punch drunk" described by Martland[16] and associated with degenerative changes in the basal ganglia, corona radiata and frontal lobes followed repeated mild concussion. The pathologic picture in this syndrome and at times the clinical picture are similar to that seen in more severe brain injury. Schaller[20] classifies as purely psychogenic such conditions as have been described as traumatic neurosis, traumatic hysteria, litigation neurosis and compensation hysteria, and refers to them as the post traumatic psychoneurotic state. Lynn, Levine and Hewson[14] devised the Columbia Head Injury Psychological Test Battery and concluded that the differences between the post-concussive patient and the neurotic could be summarized as follows:

1. The rate of new learning and of forming new associations is slow in the post-concussive patient, sometimes slow but often normally quick in the neurotic.
2. Arithmetic problems and number tasks are usually difficult for the post-concussive and easy for the neurotic patient.
3. Spatial perception is generally good in the post-concussive state, sometimes good but often poor in the neurotic.
4. In creative thinking the post-concussive patient is trite and lacking in individuality, the neurotic is underproductive and peculiar in his ideas.
5. In social judgment, general information and emotional control the post-concussive patient is generally normal, the neurotic below normal.
6. Variability of quality of performance is generally minimal for the post-concussive patient but is apt to be exaggerated in the neurotic.
7. Logical analysis is usually well preserved in the post-concussive patient but is often replaced by illogical and impressionistic responses in the neurotic patient.

Patients with inadequate personalities or constitutionally inferior nervous systems in whom a group of symptoms develop referable to their head injury may be classified as patients with true traumatic neuroses. Wechsler[27] refers to these as traumatic hysteria and retains the term traumatic neurosis for a group of previously normal individuals in whom a group of symptoms have developed following a head trauma without any evidence of a brain damage. He describes this as a very small group (five of 100 patients). Whether we accept Wechsler's[27] definition or not, it remains true that the diagnosis of a post-traumatic hysteria (or neurosis) must rest not alone on negative evidence of organic brain damage but on positive evidence of a previous neurotic personality with preferably a history of previous neurotic episodes.

Malingering is generally considered to be rare and does not need to be considered here except in differential diagnosis. The malingerer consciously simulates symptoms of organic disease in order to reap financial gain. He is rarely content to confine himself to subjective complaints; he usually attempts to simulate organic disease and it is usually easy to uncover his deception. The most important requisite to recognition of malingering is the recollection of its possibility. Keschner[13] has well covered the details of detection of malingerers in relation to brain trauma.

Treatment. The treatment of mild head injury has two objectives. The first is observation of the patient for the complications of extradural or subdural hemorrhage. The second is the prevention or cure of the post-traumatic syndrome. Failure to achieve the first of these objectives will result in the death of the patient. Failure in the second objective will not cause a fatality but is costly in terms of suffering to the patient, time and wages lost, and compensation allowed in industrial cases.

All too often the management of the patient with mild head injury may be summarized as—too little early, too much late. More intensive early therapy has not only physical but also undoubted psychologic value to the patient.

Patients with mild head injury who have no subjective symptoms may be ambulatory after twenty-four to forty-eight hours. To keep such patients in bed is to suggest that they are more seriously injured than they have been told or that serious complications are feared. This may well become the basis for

neurosis, especially in unstable patients. On the other hand, it is equally wrong to disregard the subjective complaints of headache and dizziness. The resentment of the patient towards what he considers the callous attitude of his physician may long retard his recovery. In addition, I am convinced that there is a physiologic basis for the headaches and dizziness that immediately follow concussion. The circulatory disturbance associated with concussion causes the temporary loss of vasomotor compensation to postural change in the intracranial cavity and in like manner may be responsible for the headaches. Rest is the best immediate treatment; however, as in many other abnormal physiologic states it must not be prolonged as then more is lost than gained, especially as regards vascular tone. Those patients with mild injury who complain of persistent headache or dizziness for more than two or three days after their injury should be placed on a strict regimen of fluid limitation with fluids limited to 1,000 cc. in twenty-four hours and daily saline catharsis. They may also receive 100 cc. of 50 per cent sucrose intravenously daily and a spinal fluid drainage may be performed on alternate days for at least four days. I believe this is of real value in preventing post-traumatic sequelae in the mildly injured patient. To be effective it must be carried out soon after the injury. Cases seen later with the post-traumatic syndrome rarely respond to this management. Prostigmine is of value in some cases as Malone[15] recommends. The injections of a solution of calcium chloride urea (Afenil) recommended by Murray and Halsted[19] produce a general vasodilation as do the histamine injections used by Friedman and Brenner.[7] These medications are all based on the concept that post-traumatic symptoms after head injury are due to cerebral vasomotor instability. Increase of cerebral blood flow will not only directly increase intracranial pressure but also may lead to increase in water content of the brain (edema) or to increased production of cerebrospinal fluid. Both White,[26] Windle[29] and their co-workers have demonstrated the increase in water content of the brain after concussion. This, of course, does not persist for more than a few days, and clinically the dehydration regimen seems of little value after the first week.

Impaired vasomotor tone may persist much longer, especially after severe injury, but there is no reason to believe that it, too, is not self-limited. Brenner[1] and Friedman[6] emphasized in their study that when symptoms of headache and dizziness persist more than two months after head injury, psychogenic factors were usually present. In dealing with patients with mild head injury (concussion) it is likely that the period during which physical factors are operative is much shorter. Therefore, management should be directed at the early correction of physical factors, but the patient must be urged to resume activity even at the cost of discomfort. He must be led to expect minor discomfort during the period of return to full activity and made to realize that such discomfort is physiologic and does not mean that he is seriously injured or in danger of permanent disability. It is often difficult to combat the dire warnings of well meaning friends and relatives and the blandishments of personal injury lawyers, but the value of early frank discussion and reassurance by a sympathetic but firm physician cannot be overestimated.

In conclusion the following program is recommended for the patient with mild head injury (concussion):

1. Careful examination and hospitalization for forty-eight hours. Roentgenograms of the skull should be made for the record and for assurance of the patient as well.

2. After twenty-four hours of bed rest the patient should be allowed up. If symptoms of headache and dizziness appear and are present for more than twenty-four hours, he should be returned to bed and for three days should receive a saline cathartic, 100 cc. of 50 per cent sucrose intravenously and a spinal puncture with removal of 10 to 15 cc. of fluid unless or until the initial lumbar manometric pressure is 100 mm. or less of water. Ambulation may then be instituted again and persisted in this time.

3. Patients who do not complain of headache or dizziness or whose headache or dizziness disappears within twenty-four hours after ambulation is begun may be discharged from the hospital. Return to their usual work within a few days, at least a week, should be insisted upon unless the work is unusually heavy or its conditions (noise and necessity of concentration) are unusually severe. In such cases either part time or light work should be

started with an early return to the usual duties (within one to two weeks).

4. Patients whose subjective symptoms have persisted in spite of the dehydration program should be placed on a program of rehabilitation consisting of steady increase in the amount of time that they are out of bed and graduated exercise consisting of stair climbing. They should not be dismissed rom the hospital until they are out of bed most of the day and can climb two flights of stairs twice daily. (It is assumed here that we are dealing with patients who do not have any degree of cardiac insufficiency.) Such a patient can hardly take to his bed at home without negating his previous activity in the hospital. When dismissed from the hospital he should be instructed to continue his increase of activity consisting now of walks. As soon as he can walk two miles, return to work should be insisted upon.

The aforementioned program is often difficult to carry out for a variety of reasons. I have not been able to use it in its entirety in many cases; but when it has been used, it has never failed to bring about an early return to work by a patient with either no subjective complaints or subjective symptoms that steadily diminished in intensity.

SUMMARY

Cerebral concussion is a mild head injury which results in loss of consciousness not to exceed thirty minutes (or a variable period of amnesia). Objective neurologic findings are fleeting. Scattered chromatolysis of nerve cells and temporary increase in water content of the brain occurs. The persistence of subjective symptoms after mild head injury (post-traumatic syndrome) can be greatly reduced if not obviated by a plan of management of initial active reduction of the water content of the brain, followed by early ambulation and graduated exercise with insistence upon an early resumption of usual activity.

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AVULSIONS OF THE SCALP WITH PLASTIC REPAIR

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AVULSIONS of the scalp may be partial or complete. While avulsions are seen in the life of every surgeon, most of these fortunately are subtotal and segments of scalp hang from the skull by a pedicle. Treatment in subtotal avulsion is simple cleansing and replacement of torn segments. Even a small pedicle frequently keeps a large flap alive because of the unusually large blood supply of the scalp.

Complete avulsions are rare today. When Montana was a frontier, scalping by Indians was probably relatively common accounting for many complete avulsions. Most of these people died after prolonged illness from osteomyelitis and infection. In modern times total avulsions are confined mostly to women employed in factories when hair is caught in industrial machines.

With total scalp avulsion immediate replacement meets with almost uniform failure because no structure as large and as complex as the scalp can be adequately nourished by tissue fluids or the poor blood supply from underlying periosteum. In a female, however, the hair may be removed and preserved for a wig. With complete avulsion every effort should be made to preserve the pericranium for the development of granulations. The outer table of the skull has a meager blood supply, and sequestra may easily develop and be very slow to separate. As soon as a patient is seen, careful cleansing of the avulsed area is necessary under anesthesia with mild soap and gallons of sterile water or saline solution. Following this, warm sterile compresses changed many times per day stimulate the formation of granulations and prepare a vascular bed for preservation of the underlying outer table of bone and for the growth of skin grafts.

Skin grafts have been satisfactorily used for seventy-five to eighty years. Autogenous grafts may be in the form of pedicle grafts, full thickness free grafts, split grafts or the small deep graft of Reverdin (pinch grafts). Split skin grafts have been the method of choice for us and most surgeons use usually the Padgett dermatome for taking the graft.

Regardless of the type of skin graft used, loss of periosteum and exposure of bone present special problems especially with regard to blood supply. No graft will grow on bare bone. As early as 1718 Heister in his Surgery suggested the use of drill holes in the skull, even down to the dura, for improving the blood supply. In more recent times surgeons have advised the use of burrholes through the outer table of bone and also even down to the dura to promote the development of granulations. It also has been advised by surgeons to remove the outer table of bone with a chisel since this is said to be followed by the active formation of granulations. It has been our observation that the thickest and heaviest granulations develop early along suture lines.

Because bone devoid of soft tissue presents such problems of circulation, attention again may be directed to the saving of skin flaps attached to even small pedicles because such skin may be brought over bone and be made to grow where no graft will take.

A recent patient of ours presented many of the problems under discussion; and since he related such a dramatic and fearful story, his experience and the ensuing difficulties will be recited in some detail.

CASE REPORT

The patient was a strong and vigorous white rancher, sixty-one years old, who had lived in the foothills of the Rockies for thirty-eight years.

On July 30th at about 10:00 P.M. he noted a commotion in the sheep and upon investigating found two grizzly bears attacking the band. He shouted at them and one bear ran away. The other bear approached and showed intentions to fight. Therefore, as the bear circled him in the light of a half moon, at a distance of about 30 feet, the patient shot him between the shoulders with the 30-30 carbine he had brought with him. The bear fell to the ground with a loud groan and lay still. The patient ran closer to shoot again; but when he pulled the trigger, the gun did not fire. When the hammer clicked on an empty

barrel, the bear leaped to his feet and before the man could retreat he was attacked. An attack from a large grizzly bear is a major castastrophe and to avoid sudden death is unusual. The patient felt his scalp being clawed from his head and his shoulders, arms and legs being bitten and hammered by the bear. He does not know how long the attack lasted, but the patient believed that he was being destroyed and would not survive.

The bear finally left the man, probably believing him dead, and the patient realized that he was losing huge quantities of blood from his wounds. He was conscious, however, and able to arise to travel toward camp for about 100 yards when he heard a growl behind him. The bear had heard his movements and returned once more to attack him. Again he was bitten and beaten, but he wrestled with the bear and they rolled down a steep embankment into a gully where again the bear left him apparently dead. His vitality was tremendous and he was again able to get up and stagger about ½ mile to his camp. Here he was able to saddle a horse and mount. He rode for five hours to his home ranch where his wounds were covered with towels and he was brought to Great Falls.

He arrived at the hospital on July 31, 1949, about 11:00 A.M., twelve to fourteen hours after his injuries, and his general condition was fairly good. His blood pressure and pulse were good, but he was pale; and when his blood-soaked towels and clothing were removed, he was a horrible sight. His scalp and pericranium were entirely torn away from his skull and large portions of soft tissue were gone. Tattered skin fragments hung down over his face and his ears were shredded and torn as they, too, were hanging in fragments. A claw had buried itself in the right ear canal and torn a hole in the canal down into bone so that bone fragments as well as cartilage from the ear were lying free in the ear. His face was lacerated and scratched. His right hand and both forearms, arms and shoulders were lacerated and deep, through and through teeth marks were visible, showing the size of the jaws and teeth of the animal. The left thigh and groin showed similar wounds.

The wounds were badly contaminated and contained dirt, gravel and pieces of grass. The sealed off wounds already showed fibrin and some purulent exudate. Since the patient's general condition was found to be satisfactory, he was taken to the operating room and given intravenous pentothal anesthesia and about 1,200 cc. of blood as transfusion. At this time castile soap and many gallons of water and isotonic saline solution were used to clean all wounds thoroughly.

Tattered skin flaps were débrided very little and were stretched to about normal tension and brought up to cover the bare skull as much as possible, suturing them over the top of the cranium to flaps on the opposite side. This left a defect 25 cm. long and 12 cm. wide in greatest diameter where bare bone of the cranium was exposed. The fragmented ears were reconstructed and sutured. Small amounts of sulfathiazole crystals were sprinkled in the wounds and tetanus antitoxin and penicillin were given hypodermically. Large wet compresses were applied to all the wounds and changed frequently.

The patient responded well and was given streptomycin and penicillin. His blood count on the following day (after two transfusions) showed 3.9 million red blood cells, 12.7 gm. (75 per cent) hemoglobin and 12,000 white blood cells. His temperature rose to 100°F. the first postoperative day, 99.6° the second postoperative day and thereafter was normal. Blood chemistry and urinalysis remained normal.

Wounds in the shoulders and extremities were not closed primarily; and when they showed signs of healing without suppuration, they were sutured. In two to four weeks the bones of the skull appeared healthy and heavy granulations were observed to be growing along suture lines, but the rest of the exposed bone was still bare. It was then decided to use drill holes through the outer table of bone to stimulate the formation of granulations. This was done on September 1, 1949, one month after the injury. It was planned to use burr holes through the outer table, but the skull proved to be so tough that burrs were replaced by a small bone drill. Holes were bored about 1 or 2 cm. apart. Two or three drill holes went through both tables of bone without harm and without any apparent benefit insofar as formation of granulations were concerned.

Warm moist compresses were continued and on September 19, 1949, one and one-half months after the injury, enough granulations were present over most of the skull that split thickness skin grafts from the right thigh were applied under sodium pentothal® anesthesia. An almost 100 per cent take occurred, the only portion failing to take being posteriorly over the occiput and anteriorly over the frontal bone where granulations were deficient and where the graft contracted. Two weeks later, after sufficient granulations had formed, these small areas were grafted and a satisfactory take obtained.

We are happy with the result; and while the patient is quite bald, he is not unhappy because he had very little hair on his head to start with.

CONCLUSIONS

1. Avulsions of the scalp today can largely be prevented by following safety rules in

industrial plants, homes and ranches. Hair nets should be used by women handling machines where hair can be caught by rapidly moving parts.

2. If avulsion has occurred, replacement of separated scalp will meet with failure of the part to grow. Therefore, such scalp should not be used as a material for coverage.

3. Hair from avulsed scalp may be rescued and saved to be used as a wig, alleviating some of the mental agonies, especially of female patients.

4. The best means of cleaning avulsed wounds is with soap and large amounts of water or isotonic saline solutions.

5. Torn fragments of scalp should be débrided with caution because the abundant blood supply will permit survival and use of such flaps.

6. Infection and formation of sequestra should be guarded against in exposed portions of bone. Warm, wet, sterile dressings stimulate the growth of granulations, eliminate infection and prevent crust formations.

7. Granulation tissue appears early along suture lines. Drill holes through the outer table of bones of the skull are useful in developing growth of granulations.

8. Split thickness skin grafts are useful in covering defects over bone when granulations are of sufficient size to support growth.

DISCUSSION OF PAPERS BY DRS. VORIS AND HOWARD

STERLING BUNNELL (San Francisco, Calif.): I should like to discuss the last paper because it is of great interest to me. A bear will attack if it is suddenly surprised, if you come on it suddenly or if it comes on you suddenly. It will attack if you get between it and its cubs, and sometimes because it has been injured by a man in the past and has a grudge against men. If it is shot with a gun that will not kill it, like a Savage or a 30-30, the bear will almost invariably attack. A Magnum will stop bears.

As to the treatment of the scalp wound, Dr. Claire Straith had a similar case of complete avulsion of the scalp. He put the scalp back again and it did not grow. He looked up all the cases in the literature and found that the scalp never grows when it is completely avulsed. He then put the scalp back again and he had to resort to split grafts.

RAYMOND HOUSEHOLDER (Chicago, Ill.): A young woman in her early twenties, who had the hair of her scalp caught in a very rapidly moving shaft, was brought in to me. Fortunately, the people who brought her in cut the scalp away from the hair, washed it off with a little boric acid solution and wrapped it up in a piece of waxed paper and brought it along. She had an area about 6 by 8 inches totally avulsed from the scalp, and there were places where the bone was laid bare. We did the most usual thing—cleaned up the area very thoroughly and replaced the scalp.

The avulsed scalp fit on like one of these little skull caps. This scalp does not grow, but we had hopes, and in due time there was necrosis. However, as it went on there was healing from the side.

Enough of this took and there was growth in from the sides so that in a matter of several weeks she had a granulating area left. This was covered with split thickness skin grafts which all took.

I lost track of this girl and found her again about two months ago. At first she had been furnished with a wig, but at this time stated she did not need the wig. There was sufficient hair on the sides which grew; she was very clever for she had piled the hair up on top of her head so that she went about with her usual duties as a housewife, hardly noticing that the top of her head had been taken off.

I should like to ask the essayist if one is so fortunate as to have the scalp brought in with the case, as we were in this instance is it worthwhile to remove all the subcutaneous tissue from the scalp and use what is brought in as a split thickness graft directly over the original wound?

CHARLES G. JOHNSTON (Detroit, Mich.): I want to say something about Dr. Voris' paper because he has presented a very serious problem following skull fractures. I quite agree with him that those patients whom we see in the city hospitals are a little less likely to have post-traumatic sequelae than those who are up and about and looking after themselves. On the other hand, city people do have them and they are exceedingly troublesome in carrying. Some years ago we tried dehydration and gave it up, believing that we got into more trouble with dehydration and it did very little good. However, I am interested to see that Dr. Voris has tried it again and that he believes he gets definite results from it.

HAROLD C. VORIS (closing): I do not think you can deny that in these patients with mild head injury the psychological value of whatever you do may be the determining factor. A review of the literature indicates that there are two generally opposing theories with many, including myself, somewhat in a compromise position.

One theory is that these symptoms are all on a physical basis, whether it be changes in the nerve cells, disturbances in the cerebral vasomotor control or an edema of the brain that is responsible for the symptoms.

The other view is that these symptoms of headache and dizziness in a mildly injured patient

are all psychologic. They represent a psycho neurosis. Of course I do not like to use the term neurosis, because of the possible interpretation of liability that is associated with a neurosis due to trauma.

I think that the experimental evidence shows that there is some fluid retention in the brain after a mild head injury and also that there are some changes, rather spotty and selective, in the nerve cells. The latter one cannot do much about. For the former I think dehydration represents the logical treatment.

I should like to emphasize again that such treatment does no good after the first few days, in my experience. I also think that it does no harm to the mildly injured patient. However you may feel about dehydration for the seriously injured patient, it is not going to hurt the kind of patient that I have talked about, but it is not worth keeping up very long.

I think that the whole theme of my presentation is a plea for a little more intensive treatment of these patients in the first few days after their injury and then a firm insistence on the resumption of activity.

L. L. Howard (closing): I am not a ballistics expert but the ranchers in Montana advise me that a 30–30 carbine has been a favorite weapon with them for many years because it is easy to handle in a saddle. I remember one man in particular who states that such a rifle works satisfactorily if one waits until the bear gets up close before starting to shoot. He realizes that the 30–30 will not knock them down like a Magnum or a 30–06.

I always said if I were going to hunt bear—and I do not want to hunt grizzlies—I would want to be in a high, strong tree before I would start doing any shooting, because I think they are very ferocious animals.

To attempt to answer the question that was asked regarding re-application of avulsed skin, I reiterate that the skin will not grow if it is re-applied. If the periosteum is intact, it is possible that a split thickness graft, if applied within six hours of the injury, might take, but I doubt it.

CONSERVATION OF THE FOOT FOLLOWING INJURY

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THE surgical verdict in the case of the severely traumatized foot all too often reminds me of that of the Red Queen in Alice in Wonderland—whatever the crime, the same verdict—"Off with his head!"

I believe that the thinking of the past has altogether too great an influence on the practice of today. I do not say the thinking of today; because if one sits down and thinks, one is appalled at the number of feet which have been sacrificed when much might have been saved.

This will sound to many of you as either the last cry of a diehard conservative or an advocacy of a return to the principles of "bow and arrow" surgery. However, I hope to present at least a case for the argument to serve as a basis for discussion.

It is so easy to become accustomed to doing certain things in a certain way that procedures may become almost routine.

Once this is allowed to happen, opportunities for improvements in methods and technics are practically nil.

It is, therefore, a good thing to take stock of ourselves from time to time to ensure that our thoughts and procedures are not becoming stereotyped.

Years ago the so-called classical amputations of the foot were developed, largely based upon major anatomical cleavages, usually through joints, and the necessity of so placing an amputation that good, full thickness skin flaps could be obtained for closure.

Admittedly, this was at the time an advance over the guillotine type of amputation and the searing of the stump with a hot iron or boiling pitch, but is or should be equally archaic today.

With the modern advances in the manufacture of prostheses and the great advances in plastic surgery, these factors have ceased to have anything like their former importance. As a consequence, the whole approach to the subject of foot amputations has undergone a fairly drastic revision.

The older amputations, such as the Chopart, Hey and Lisfranc, rather failed in their purpose because of the lack of skill and ingenuity of the prosthesis maker and gradually fell into more or less disrepute. Indeed, in many centers they are merely mentioned to be condemned.

During the 1914 to 1918 war the Symes became a very popular amputation, and in some centers is still regarded as one of the most satisfactory.

Actually, if one studies it, it is not a sound amputation in a modern conception. It was designed in the days when an end-bearing stump, which would require little or nothing in the way of a prosthesis, was the aim of the surgeon.

Granted that for the type of individual who would be content to wear an "elephant boot" it is a cheap and easy thing to maintain. However, very few people nowadays will consent to wear such a hideous monstrosity and any prosthesis which attempts to supply an artificial foot and some ankle motion must be extremely clumsy.

Also, experience at Roehampton, to which center came all the amputees in the United Kingdom, has shown that on the average the Symes is a ten-year amputation. The majority require reamputation because of ulceration of the heel pad at about that time.

It would appear, therefore, that in dealing with foot injuries one should scrap all one's preconceived ideas and deal with each individual case on its own merits.

As much tissue as is viable should be preserved, and the sacrifice of bone structure in order to obtain flap closure should not be countenanced. Nor, is there any necessity to disarticulate the bases of metacarpals even though the heads and distal transverse ligaments may have been destroyed or severely damaged.

Equinus or varus deformities may be overcome or, better still, guarded against by appropriate operative measures to obviate tendon imbalance when the normal insertion of one

tendon has had to be sacrificed, and the aid of a skilled prosthesis maker must be sought.

It is amazing to me how well a foot, in which the normal architecture of the arches designed to meet with the various stresses and strains of locomotion has been largely destroyed, will adapt itself to exceedingly adverse conditions and render useful service, often with only minimal assistance by artificial aids.

In considering the treatment of patients suffering from trauma to the foot, some consideration should undoubtedly be given to the social and economic status of the individual. In some cases it may be necessary to sacrifice part or even all of a foot in order to shorten the period of treatment and disability, but in general I believe it is true that, to paraphrase, half a foot is better than no foot.

This, I realize, is heresy, since the fiat apparently has gone forth that amputations back of the metatarsal heads are unsatisfactory. However, I submit that that verdict was largely rendered by a jury of our fathers, who had what we would now describe as next to no facilities at their disposal, and at a period when a patient's discharge from the surgical ward practically terminated treatment.

Fifty years ago and even less there were few, if any, physiotherapy or rehabilitation departments as we now understand them, and the designing, fitting and upkeep of prostheses was practically in its infancy.

Therefore, it would appear that conditions have changed sufficiently to warrant an appeal from this verdict and a challenge to our surgical skill to see if we cannot create from an injured foot something which will enable the patient to go about his business with the minimal use of hooks, springs and mirrors.

I appear to have talked a good deal and said very little, but in essence the appeal is to discard all past shibboleths and evaluate each case seen on its own merit, with the following criteria always in mind:

1. How severe is the damage? This is something that is often extremely difficult to assess until long after injury, as those of you who have dealt with electrical burns, trench feet and frostbite will agree.

2. What is the vascular condition? I would be the first to decry conservatism in the patient with an inadequate vascular tree.

3. The age of the patient? "You can't teach an old dog new tricks" and it is useless to attempt to re-educate an octogenarian.

4. The economic status? Is it possible to carry out long-drawn procedures in the hope of a better end result or must one cut one's losses?

5. The social status? Some people hardly use their feet anyway, and a reasonably high amputation with a neat prosthesis may be preferable.

On the evening of December 23, 1946, an aircraft carrying six passengers and the pilot left the Gulf of St. Lawrence to cross to Mount Joli. Approximately halfway across there was engine failure and a crash landing in the icy waters, dotted with fair-sized floes.

All of them managed to swim from the wrecked aircraft to ice floes. The pilot was forced to kick off his flying boots and was left with silk socks and patent leather shoes.

Six of these seven men were rescued by flying boats—three after a mere thirty hours' exposure on the ice—the next three after sixty hours and a drift of sixty miles.

All were sent to Montreal suffering from various degrees of frostbite. These patients were all treated expectantly with the use of anticoagulants, lumbar blocks, ATS and antibiotics. Part of the treatment, also, was keeping the parts cool. Some had Pavaex and some had rhythmic constriction until lines of demarcation formed.

The three most severely injured patients were: (1) the pilot who required a lop amputation in February, 1947. One of the most important features in this case is that, according to regulations, this boy could never fly again commercially unless he had at least half a foot. He has been able to do so although he has since been retired owing to hypertension. (2) A woodsman who lost all his metatarsal heads on the left foot. He could not go back to the bush, but now has a clerical job, drives his car and his only prosthesis is a small foot plate in his left shoe. (3) A timber cruiser who lost all his toes on each foot, plus the heads of the first and fifth metatarsals on the right. He also has had to change his occupation and is now a successful mink farmer.

DISCUSSION

BARBARA B. STIMSON (Poughkeepsie, N. Y.): I think Dr. Elder's paper brings up something that

we should all think over very carefully. I know that I was very much impressed by the need for early amputation of some of the severely injured feet that I saw. I am not sure whether we were wise, in view of what Dr. Elder has said, because possibly some of those feet might have been saved.

On the other hand, I think a word of caution should be mentioned because, undoubtedly, some of the patients with injured feet who have suffered not only vascular damage, such as frostbite, but also bone damage with infection, where an attempt has been made to save them, have gone on for months and months of hospitalization and have been unable to walk because of the very painful plantar scars. In those instances, I think probably early amputation might have saved time and a great deal of money.

There have been cases in which a Syme's amputation has helped out. I remember one patient very vividly because not so many years ago he stopped by in New York to see me on his way West. He was a South African who had crossed a mine field in a tank, one leg had been blown off and the other foot very badly damaged, and he reminded me that several of us had stood around his bed, arguing. Apparently I was arguing for a Syme's operation and the rest of them were arguing for a higher amputation. The Syme's won out on his remaining foot, and he had been able to learn to fly, to dance and to go out to Chicago for a nine months' training course in an industry there, where he was on his feet (artificial) for eight to nine hours a day. He stopped by in New York on his way through to tell me how much he appreciated his Syme's, because two mid-leg amputations would have made him completely helpless, whereas with his Syme's he could hop if he had to.

I think the main thing, as Dr. Elder has said, is that these cases must be considered on their individual merits and that immediate amputation should be used only in the most serious cases in which, obviously, nothing can be saved. I think Dr. Elder has done us a great service in reminding us that new things, new prostheses, new methods of rehabilitation, may change our old concepts of surgery.

George J. Curry (Flint, Mich.): I would like to allot the period of time that is customarily given to a discusser to Dr. Woughter who I believe knows a great deal more about amputations than I do and is much better qualified to discuss this very excellent presentation.

H. W. Woughter (Flint, Mich.): This is a surprise to me. I do not know whether or not Dr. Elder knew it, but he is talking about this subject within sixty miles of an amputation center established during the war at Brigham City, Utah, in which we took care of 3,500 amputation cases.

It is difficult to criticize Dr. Elder's paper, knowing the meticulous manner in which he enters into any subject. I would like to say a few words in defense of the Syme's amputation as we knew it in the Army. There was a controversy going on during the war between the British, Canadians and Americans as to the value of Syme's amputation. We did many of them and believed it was a very good amputation.

However, in comparing notes with the other centers, and especially with Dr. Rufus Aldridge in the East, we believed that the original amputation as described should be altered in some respects in order to put the transsection of the bone a little closer to the joint and, in fact, to go through the ankle joint, taking off the two malleoli and leaving about the size of a quarter of the cartilage at the end of the tibia.

It is the most meticulous amputation in order to get the results, of any of the levels. You must preserve all of the blood supply, and the pad on the end of the bone must be placed so that it will not slip from one side to the other; in other words, the value of the Syme operation seems to be in direct proportion to the skill of the person doing the amputation, plus the skill of the prosthetic makers and their ability to fit the prosthesis.

The Chopart's amputation, or just leaving the hind foot, of course, has always been considered a very poor amputation because the foot eventually goes into inversion and equinas and requires an elephant foot type of prosthesis. However, if one can save the heel pad and keep the hind foot in a relatively normal position, it is the type of amputation that will not wear out. Therefore, we thought that by doing the Galli fusion of the subastragalar joint a collapse and fusion of the ankle by osteotomizing the fibula and turning it down for access into the joint, thus making the circumference of the ankle approximately 1½ to 2 inches less than the normal, we could stabilize the hind foot in its normal position and at the same time, by making the ankle so much smaller, we could fit a prosthesis, the ankle of which appears very close to normal.

Jere W. Lord, Jr. (New York, N.Y.): Dr. Elder certainly has made a most important point in his conservative management, and I would like to enforce that from a different point of view. My own experience has not been with traumatic amputations as he is discussing, but with arteriosclerotic occlusive disease.

Our work at Bellevue, in the Postgraduate Division, has been influenced by Dr. Franseen and Dr. McKittrick's work in Boston in regard to their transmetatarsal amputations, and the cases have been done for diabetic and non-diabetic gangrene of one or more toes with involvement of the web space.

A small series has been done and successfully healed stumps have occurred in about three of four cases in a series of about twelve patients.

When successful, the foot resembles one of the feet that Dr. Elder showed, the amputation being carried out just proximal to the distal ends of the metatarsal bones and a long plantar flap brought back so the suture line is just dorsal to the end of the foot. Walking is excellent. We have had no secondary breakdowns, although the series has been done only in the last two years.

As Drs. Franseen and McKittrick have pointed out, if failure occurs, one can still go to a higher amputation. From my own personal experience with patients who have had lower leg amputations and ones above the knee, from the economic point of view, from three to six months usually takes place before the stump is healed, it has been fashioned into a cone shape, the limb has been fitted and the patient can walk well. Therefore, in this type of patient one can afford to take some time to try to obtain a useful foot for ambulation.

H. M. ELDER (closing): To Dr. Woughter I would say that I deliberately tossed in the Syme's operation as a controversial point, because it is a controversial point, and I think it is one that is well worth our thinking about and talking about.

As of last week the feet of the woodsman did not look abnormal but he walks with a certain amount of limp. He does not have to use anything except the small foot plate in one shoe.

The timber cruiser, a woods engineer, got away with the loss of all his toes and on one foot the first and fifth metatarsals. I located him just before I came down here. He had to change his occupation and is now a comparatively successful mink farmer.

TREATMENT AND REHABILITATION OF THE PARAPLEGIC*

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EACH one of us can recall patients of our own who have had transection of the cord and in whom gradually progressing inanition, ulcers, urethral fistulas and urinary tract infections developed. They were considered hopeless by their family and doctor, became dope addicts and finally after about a year of total misery death was welcomed by all concerned.

In recent years with the help of antibiotics and increased knowledge of the physiology of paraplegia the picture has completely changed. It is not only possible but also the patient has a right to expect that he will be restored to health and that with sufficient effort on his part he may again take his place in gainful and pleasurable living.

The treatment of paraplegia is a mosaic in which many specialties contribute their certain parts. The neurosurgeon and orthopedist share the treatment of the initial lesion, the internist maintains nutrition, the urologist controls urinary tract infection and bladder complications, the plastic surgeon closes ulcers and the physiatrist directs rehabilitation. These phases are equally important and successful treatment depends on the cooperation of these specialists or when only one doctor he must be well informed on all of these phases.

It is not surprising, therefore, that the greatest advances came during the past war when there were two factors present; first, a large number of paraplegics and second, large general hospitals in which they could be collected and treated by a group of specialists all of whom were interested in the problems of the paraplegic.

Such a center was Kennedy General Hospital and it has continued to be a paraplegic center under the Veterans Administration. Patients treated during the past four years include 178 inherited from the Army, plus 424 new patients, or a total of 602 patients. In treating these certain procedures have proved advantageous and will be presented as a working basis for treatment.

On admission the neural and skeletal lesions are evaluated by the neurosurgeon and orthopedist. In cervical lesions Crutchfield tongs are inserted in all except mild partial lesions. An immediate laminectomy is done if there is complete spinal fluid block or laminal fracture. If the injury is over twelve hours old, the operation is postponed about one week while the patient is kept in traction provided there is no progression. If a block is not present, he is continued in traction. If there is evidence of instability or derangement of the apophyseal joints in the form of subluxation or marked compression, a fusion is done with or without laminectomy. In the thoracic and lumbar regions laminectomy is the rule plus fusion if unstable. Late laminectomy, i.e. after two weeks, has given discouraging results except in the lumbar region in which the lesion is like that of a peripheral nerve.

Aside from the initial lesion treatment consists of prevention of complications, correction of complications and instruction in compensating for functional loss. These phases are carried out simultaneously and are interrelated; for example, if complications are successfully prevented, the rehabilitation proceeds more rapidly and the patient may go home much sooner. There are six primary factors in the general treatment to avoid complications.

1. *Maintain Good Urinary Drainage.* Residual urine leads to infection and it is urinary tract infection that kills these patients. Tidal drainage as described by Munro[1] is used and the catheter changed every three days. Since the catheter is a source of irritation tending toward infection, it is removed as soon as the patient can get along without one. Usually at

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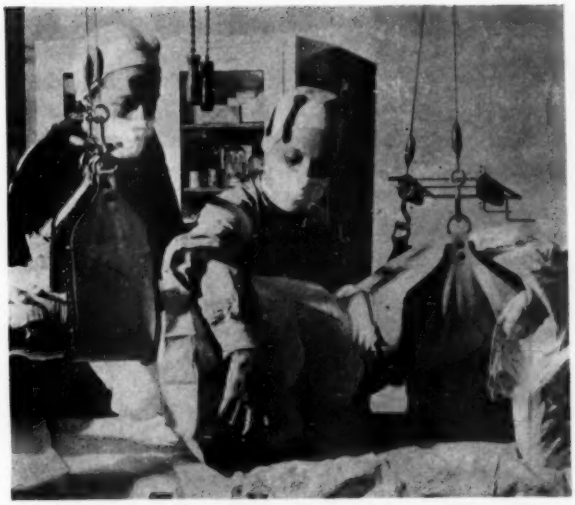

FIG. 1. Dressing decubitus ulcers about the pelvis is facilitated by electric hoist.

FIG. 2. A chain reaction; adductor spasm, dislocation of hip, trochanteric ulcer, pyarthrosis. Also shows intertrochanteric fracture if too much bone is removed in ulcer closure; ischial tuberosities have been resected.

about four to six weeks in the patient either a reflex or automatic bladder develops. If after removing the catheter for a day there is a residual of over 60 cc., he still needs a catheter or an operative procedure is indicated. Spastic detrusor or sphincter muscles may be improved by selective sacral rhizotomy[2] and contracted sphincters by bladder neck and external sphincter resection. Sometimes both procedures are indicated in the same patient. A cystogram is advisable when removing the catheter to rule out reflux of urine into dilated ureters. When this exists a suprapubic cystostomy is used in some cases to provide better drainage. Suprapubic cystostomy is also used in many quadriplegics, since they cannot manually assist in emptying the bladder. Infections are treated with antibiotics; and since many of our cases are resistant to streptomycin, the one most used at the present time is aureomycin. Infection leads to stone formation. Bladder stones are treated with lithotripsy, small renal stones in the calices are observed, free stones blocking the ureter and staghorn calculi are removed.

2. *Turn the Patient.* It is seldom that a normal person sleeps all night in one position but turns several times even in his sleep. These patients lack both the sensory stimulus and ability to turn. If not turned about every two hours the skin over the pressure points will break down and a decubitus ulcer will form. Dressing of the ulcer patient is greatly facilitated by an overhead electric hoist so that bandages can be wrapped around the pelvis without lifting him for each turn. (Fig. 1.) No certain time can be set as the best for the closure of ulcers. The sooner they are closed, and the loss of serum protein through them stopped, the better will be the general condition. However, the more the patient can be built up first the better the chance of the ulcers staying closed. In closing an ulcer the lesion is excised along with infected periosteum and it is advisable to resect some of the bony prominence. Opinions differ regarding the amount of bone to remove. If ischial tuberosities are not resected down to the obturator foramen, ischial ulcers may recur. On the other hand, if resected this far, the formation of new ulcers posterior to the greater trochanters is not uncommon. Removal of too much bone from the trochanters may result in fracture. (Fig. 2.)

The tendency to form ulcers is increased by low serum protein, anemia and also cachexia since loss of subcutaneous fat makes the bones more prominent.

3. *Feed the Patient.* During the early stages the patient is in marked negative nitrogen balance while his muscles undergo atrophy and his appetite is poor. He must be urged to eat, his diet must be high in protein and his family

should be consulted regarding his favorite foods. Serum protein can usually be maintained by adequate diet and we now transfuse only for severe anemia because of the frequent complication of homologous serum jaundice.

4. Get the Patient Out of Bed. This is the most important preventive treatment for the urinary tract, cutting down residual, infections and stone formation. We aim to get him into a wheelchair by six weeks and ambulating by three months. Another idea we are trying is to fasten wood supports on the end of the Stryker frame and stand him up—frame and all. This has possibilities as an early aid to kidney drainage.

5. Control the Bowels. Cleanliness of the skin is important in preventing ulcers so that bowel control is necessary from this standpoint as well as to make the patient socially acceptable. Some advocate the use of glycerine suppositories or digital stimulation, but we have obtained better results by using an enema every second or third day. This is simplified when given through a Bardex-Verdin or Foley type catheter to prevent leakage around the tube. On this regimen the patient can go out in public without fear of soiling.

6. Withhold Opiates. It has been the custom in the past to give opiates to these patients freely since there was no hope for recovery. These drugs should now be used with the same care as in other chronic illnesses and only for sufficient reason, such as following surgery. Unremitting pain is treated surgically. Exploration of the cord lesion with freeing of adhesions will help many patients. Cordotomy gives complete relief in a high per cent of patients but is good only for lesions below the eleventh dorsal segment. Sympathectomy, according to Munro,[3] relieves a few patients in whom the pain is of vascular origin, but in general the results have been discouraging. Posterior rhizotomy has been totally unsuccessful and is not recommended. Prefrontal leukotomy has not been tried in any of our cases.

Another condition which at times requires neurosurgical intervention is that of spasm. This is not found in cauda equina lesions but only in those of the cord. While originally thought to indicate a transection of the cord it is now known to bear no relation to the completeness of the lesion. A small amount of spasm is advantageous maintaining muscle tone, circulation and nutrition in the extremities. If severe enough to cause pain or interfere with ambulation anterior rhizotomy is indicated. The roots from T12 to S1 are divided leaving the abdominal and also the bladder innervation provided the patient has a satisfactorily functioning reflex bladder. If the patient refuses rhizotomy or if the condition is early so that some return might still be expected, a sciatic nerve crush is performed. This relieves the spasm for approximately six months.

The integrity of the hip joints is of utmost importance to paraplegics since ability to be up in a wheelchair is a prerequisite to rehabilitation. A most serious complication, therefore, results from trochanteric ulcers in the form of infection spreading to involve the hip joint and adjacent bone of the femoral head, neck and the acetabulum. (Fig. 2.) If recognized early the resection of only a portion of the head and neck may suffice, thereby retaining a satisfactory joint. However, it is more usual to find the destruction far advanced by the time this lesion is recognized as the source of the patient's temperature and total excision of the hip joint is necessary. If abdominal flat plates were routinely made to include the hip joints, the early diagnosis of this condition would be more common.

Another bony lesion involving the hip and to a lesser extent the knee is a characteristic form of myositis ossificans in which heavy bony bridges are thrown across the joints. The pathogenesis of this condition is not yet understood. Blood calcium, phosphorus, alkaline and acid phosphatase, and vitamin C levels are normal. In patients in whom it occurs the condition is exceedingly persistent and solid bony ankylosis is difficult to prevent. It is curiously more prevalent in the colored race.

When the possibility of ambulation is precluded by chronic infection in a weight-bearing joint or by ankylosis of the hip, the patient is better off with bilateral high thigh amputation. Relieved of the burden of useless extremities and able to sit, he can then rehabilitate to the full extent of the wheelchair patient. These patients with the help of a few modifications in their homes can be entirely self-sufficient.

The extent to which a paraplegic can be rehabilitated and the speed with which it can be accomplished depend on two factors, namely, his will to recover and his physical condition. The progress is retarded by any psychic or physical complications. The psychic adjust-

FIG. 3. Immobile hand of quadriplegic who had good return of function; was freed by capsulotomy.

ment is more rapid in the mature individual, in the one who has already learned to work and whose family understands and accepts his condition. It is delayed by any pessimism on the part of the doctor or the family. The family often believes he will be a burden or it cannot afford to care for him when in reality he can look after himself. The enlightenment of the family should be begun by the social worker immediately on admission. Compensation in the form of pensions is unfortunately a deterring influence in many cases and we see the paradox of the non-service connected having an advantage in not being so well off. Any complication or operation which confines the patient to his bed not only delays his rehabilitation a given number of days but also tends to instill an attitude of invalidism which further retards his progress.

Rehabilitation is under the direction of the department of Physical Medicine with its five departments of Physical Therapy, Corrective Therapy, Occupational Therapy, Educational Therapy and Manual Arts Therapy.

Physical therapy is begun immediately with a muscle examination. Heat and massage are not routinely used, but passive motion is checked weekly as long as a normal range is present. Daily treatments are given if contractures begin to develop.

Occupational and educational therapy are begun on the ward if the patient's condition permits, and he is allowed little time to brood over his misfortune. Treatment is continued with better facilities in the departments after he is up in a wheelchair. He is then interviewed by the man in Vocational Guidance, given an aptitude test and advised concerning his future occupation. Interests and aptitudes are further developed in Manual Arts Therapy where he can learn the fundamentals of watch repair, radio repair, printing, wood working, metal and plastics, automobile repair and photography. While so doing his standing tolerance is developed by working at a bench while supported by a wide leather strap.

While quadriplegics cannot recover to the same degree as the paraplegic they can learn much in looking after their own needs. Much can be done surgically to improve the hands by capsulotomy, tendon transplants and tenodesis. (Fig. 3.) When the hands cannot be made to function, splints may be applied which hold the toothbrush, razor, spoon, pen, thus aiding in self care. A tray with holes to anchor the dishes is helpful when the patient feeds himself. (Fig.

FIG. 4. Quadriplegic eating with aid of plastic splint: can also be used to hold pen, pencil, toothbrush and razor.

FIG. 5. Paraplegic is taught early how to get from bed to wheelchair and back again.

4.) A plastic page turner which is held in the teeth is another great asset.

After getting up in a wheelchair at about six weeks the paraplegic patient embarks on a graduated course of instruction in self care under Corrective Therapy that occupies the rest of his hospital stay. Among other things he is taught how to get from his bed to the wheelchair and back again, to get from wheelchair into bath tub and how to get in and out of soft upholstered chairs. (Fig. 5.) He learns to drive a car and how to pull the wheelchair into the car after him. Two to three months of working several hours a day is necessary to learn crutch walking with braces and develop balance. In so doing he also becomes accustomed to walking on different surfaces such as carpet, polished linoleum or gravel, how to get up if he falls and how to go up and down stairs. (Fig. 6.) He learns how to open screen doors, go through revolving doors and as he leaves the hospital he continues to open doors literally and figuratively in all phases of life.

FIG. 6. With strong arms and sufficient perseverance a paraplegic can master stair-climbing.

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SUCTION SOCKET PROSTHESIS FOR ABOVE-KNEE AMPUTATIONS

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AT the last annual meeting of this Association it was our privilege to present an interim report on the Veterans Administration Experimental Suction Socket prosthetic research program. On this occasion it seems appropriate to record a final report which has resulted in the approval and adoption of this device as an item of issue to selected above-knee amputees.

Certain criteria for selection of cases for this type of prosthesis were previously described;[1] certain essentials of proper fitting and alignment were likewise illustrated and the results in a series of 211 cases were tabulated. In this earlier series, yielding a complete failure incidence of 4.3 per cent, it was considered that an inadequate number of patients (58 per cent) had been wearing this device for too short a period of time (four months or less) to judge the end results adequately. Today, however, one can report a greater experience in number of cases and in fairer comparisons.

First, it seems of interest to report a follow-up on the original 211 patients. This is shown in the following table:

TABLE I*

Region No...	1	2	3	4	5	6	7	8	9	10	11	12	13	Total	Per cent
Wearing routinely.....	0	6	14	10	8	12	8	10	15	3	12	56	8	162	77
Alternating...	0	0	0	0	4	0	0	0	1	0	1	7	0	13	6
Failures.....	0	2	1	1	5	4	2	3	4	1	5	7	1	36	17
Totals.....	0	8	15	11	17	16	10	13	20	4	18	70	9	211	

*April 1, 1949,[1] failure, 4 per cent; routine, 82 per cent. April 1, 1950, failure, 17 per cent; routine, 77 per cent.

The change during one year in the status of this initial group of veteran amputees is due to several factors. Not the least is the fact that more adequate information based on periodic inspection was available through the orthopedic clinics which have been established throughout the country. In many localities the limb fitters were not experienced with this type of socket, which admittedly requires more knowledge and skill to obtain maximum comfort and correct alignment. If attention is centered on the per cent successful or routine wearers, the change from 82 per cent to 77 per cent during a one-year period resulted from individuals who had worn the leg less than four months and who had not attained a successful fit.

Including with the earlier cases those amputations with prescribed suction sockets since then, there are on record at the University of California the following:

TABLE II

Prescribed suction sockets.....	688
Fitting in progress.....	66
Patients awaiting fitting.....	14
Deaths.....	2
Completed cases.....	606

In the final tabulation of success and failure, among the 606 patients in the Veterans Administration Experimental Program, the following is presented:

TABLE III

	No. of Cases	Approximate Percentage
Wearing routinely.....	445	73
Alternating.....	84	14
Failures.....	77	13
Total.....	606	100

The longest period in which a suction socket has been worn in this series of over 600 patients is forty-one months. Thirty-four patients have been wearing it for twenty-four months or longer, ninety-six patients for eighteen months or longer, and a total of 207 patients for twelve

or more months. With this experience it is believed that adequate appraisal of the device can be made.

The suction socket type of suspension for above-knee legs provides the amputee so much improvement over the conventional type with pelvic band and hip joint previously used that there never has been any doubt as to its desirability. The major question concerned the long-time effect of reduced atmospheric pressure on the stump and possible medical difficulties. In addition, there was the possibility that so much additional time would be required on the part of both the amputee and limb fitter to achieve a satisfactory fit, including necessary changes due to stump shrinkage or growth with continual use, that the advantages would not be worth the effort and possible additional cost.

Early in the program it became evident that the benefits desired were worth the effort involved for the great majority of those interested. There will always be individuals who become discouraged and revert to a conventional leg, but this has very seldom happened after a satisfactory fit has been worn for a period of several months and the benefits fully realized. As greater experience is gained by qualified limb fitters, the time required and the number of trips to the shop is reduced, with greater satisfaction to both the patient and the manufacturer. In the present series of cases the time required and the problems encountered through lack of experience proved the principal cause of most of the failures, although other reasons may have been given.

In addition to correct advice from the prescribing surgeon regarding the suction socket, it is necessary to emphasize the part played by the limb fitter. Those who are sympathetic with the patient and enthusiastic enough about the suction socket to master problems of fitting and alignment as they arise will have satisfied customers who will continue to use the suction socket leg efficiently. Those who do not have this genuine interest will have indifferent success and eventually fit a suction socket only when the patient insists. At the present time the standard above-knee leg built by some manufacturers is equipped with a suction socket, with pelvic band and joint suspension used only because of contraindications and at the surgeon's request. This reflects the experience in Germany where the suction socket has been used in considerable numbers for the last fifteen years and where the manufacturers are divided into two groups, namely, those who use it nearly exclusively and those who seldom make one, with the largest firms and most satisfied customers resulting from the first group.

The main advantages of the suction socket type of prosthesis have been discussed previously.[1] Since control of the prosthesis depends on the remaining muscles in the stump and about the hip, better physiologic balance is maintained and improved function results. The hip joint may now function normally in all degrees of motion without decreasing the "sitting" comfort during weight-bearing. Of particular importance is the lack of restraint to the motion of rotation which has been shown to be a major item in normal locomotion for rhythmic, symmetrical movement.[2] Reduction in piston action between the stump and socket provides additional toe clearance without unsightly and tiring trick motions. With the elimination of the uncomfortable harness and the stump sock, the reduction in feeling of dead weight and the improved control and position sense, the principal improvement remaining to be made in the above-knee prosthesis is the provision of knee stability. This is at present in the process of development under the direction of the Advisory Committee on Artificial Limbs with some reasonable solution expected during the coming year.

It is considered that the question of possible medical difficulties resulting from long-time exposure of the stump surface to reduced pressure has been adequately answered. There has not been a single case known in which trouble developed attributable to this cause either in this country or abroad where use extends to more than fifteen years. Stump growth has sometimes resulted in constriction producing edema which resulted in temporary stump breakdown if the socket was not properly relieved, but this should not be blamed on negative pressure.

Pressure variations within the socket have been of considerable interest from the standpoint both of maintaining proper function in holding the leg on securely and in preventing excessive suction. Figure 1 is a typical record of variation in positive and negative pressure for one subject during different walking operations and for stump muscle flexion only with the leg suspended (weight-bearing between each mus-

cular contraction). Records (a) and (b) for level walking were taken on successive days and reflect a small difference in the way the leg was put on. In both cases the negative pressure did not exceed 2 pounds per square inch and that occurred immediately prior to heel strike. As soon as weight is transferred to the leg, the pressure becomes positive and remains so until the start of the swing phase. Record (a) may have resulted from an excessively hard step on the leg which forced more than the normal amount of air out through the automatic expulsion valve which was set at 1 pound per square inch, but which will be recovered through slow leakage of air back into the socket. The negative pressure is not affected since it is a function of weight of prosthesis, cross-sectional area of the stump near the lower end where the seal becomes effective, and the fit of the socket as it accommodates muscular contraction. Records (c) and (d) were taken while the subject took one step at a time (not step over step) and illustrate the added muscle contraction required in going upstairs.

Some difficulty has been experienced with high negative pressures resulting from muscular contraction. Records as high as 11 pounds per square inch have been obtained. It is known that 3 pounds per square inch peak values have been tolerated for many months, together with the compensating positive pressures, but it is considered desirable and possible to limit values to approximately 2 pounds per square inch. High values can only be obtained when a force is present to produce them, and the principal source is expansion of the muscle belly against the side walls of the socket tending to force the socket off the stump. If a functional socket shape is used which permits this muscular activity, the negative pressures can not only be kept normal but also the muscles themselves can assist in holding the leg on.

Some attempts have been made to use a double acting or "breathing" valve to limit peak negative pressures, but this has been shown by research to be unnecessary and undesirable. Instead, the magnitude of the negative pressure during muscular contraction is one effective criterion to apply for proper socket fit.

In reviewing this experimental program it is again necessary to emphasize that the suction socket prosthesis was fitted by specially trained surgeons and limb fitters and that criteria for selection of types of stumps, as set forth one year ago,[1] should be adhered to. If all factors are controlled, one might expect in a large series of cases an incidence of failure of not greater than 13 per cent. The Veterans Administration has approved this device for selected above-knee amputees, prescribed, fabricated and fitted by skilled orthopedic surgeons and certified limb fitters.

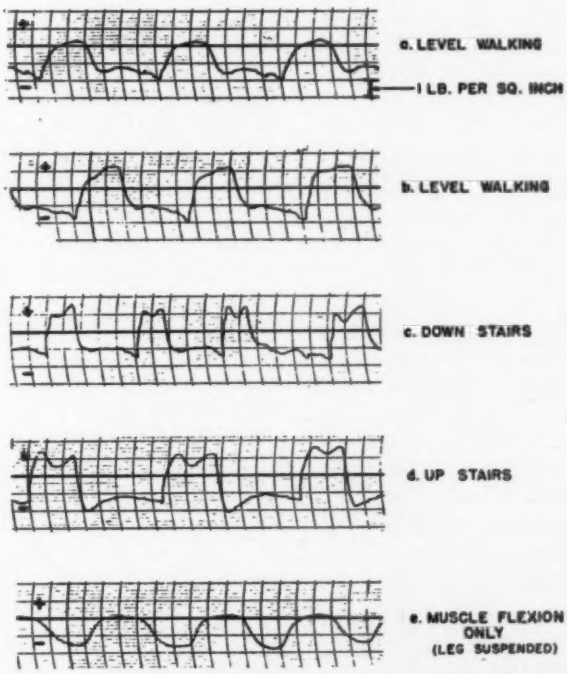

FIG. 1. Pressure variation inside the suction socket sample records from one subject.
→ Direction of walking |←1 sec.→|

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DISCUSSION OF PAPERS BY DRS. STREET, AND THORNDIKE AND EBERHART

L. W. FREEMAN (Indianapolis, Ind.): Dr. Street has done an admirable job of outlining the treatment and rehabilitation of the paraplegic patient. I could go on for the entire three minutes allotted me, pointing out the various features that he emphasized. However, there are several points on which I will dwell only slightly.

The first is that of interlocking care. In general, in the civilian hospital one finds that the patient is transferred from service to service. This prolongs the period of hospitalization and, in many instances, makes complete rehabilitation almost impossible. Of patients such as those treated by Dr. Street, over 50 per cent can be completely rehabilitated.

In a series of 112 patients whom we have followed after they have gone home, we have attributed the occasional failure of complete rehabilitation largely to personality instability on the part of the patient. We have patients in medical schools, in law schools and many in college.

The importance of weight-bearing in ambulation must be constantly borne in mind, largely because immediately upon recumbency, calcium excretion reaches tremendous levels, four and five times that of normal excretion. This brings about the formation of stones, along with the infection. By early ambulation this can be diminished and almost totally abolished as a hazard.

The importance of immediate laminectomy must be stressed. However, the laminectomy must be performed extremely carefully since in many instances the trauma of the operation itself may be more severe than the original injury. One must bear in mind the possibilities of regeneration of the spinal cord. This has always been said to be an impossibility; yet, in our laboratories we have demonstrated conclusively that regeneration does take place in rats, cats and dogs. Therefore, with the maintenance of good health in these patients we may see some regeneration in the future.

I should like to ask Dr. Street just one question. How frequently does he see fractures of the tibia, for example, in patients who ambulate only infrequently?

Frederick A. Jostes (St. Louis, Mo.): Too few doctors of medicine today are cognizant of the possibilities these patients offer. One must remember, of course, to use the proper psychologic approach to both the patient and the family. When one has seen hopeless cripples turned into serviceable individuals, one is made into a believer. So many times I receive telephone messages of people saying, "Well, why can't our patient be treated in a hospital? Why is it that only the Veterans hospitals can take care of these people?"

Now almost every private hospital could do this work. You do not need the elaborate equipment that some of our larger rehabilitation centers have. You can do a great deal with good common sense. Also, too many of us are too lazy to spend the energy and the thought needed to help these unfortunate people.

The presentation this morning gives us an excellent example of what can be done and how to do it. The essayist is to be congratulated.

William G. Kuhn, Jr. (New Brunswick, N.J.): It has done my heart good to hear Dr. Street's paper and realize that the work that began in the last world war is still being carried on and is advancing. I would like to add a few comments and perhaps suggestions and see if Dr. Street agrees or can help us further on some of these problems.

With regard to the genito-urinary tract, during the war I found out that M and G solutions, as used by the urologist, are quite irritating to the bladder mucosa. We found that alternating weeks on tidal drainage of boric acid solution and then a 1 to 500 acetic acid solution aided in cutting the mucus formed about the catheter and prevented plugging of the catheter.

On the matter of decubiti, I wonder if Dr. Street thought of a prophylactic rounding off of the ischial tuberosities, or if it has been considered in the large groups that are still remaining in veterans' hospitals.

Dr. Street mentioned the exostoses that often form about the trochanter. I reviewed a series of 122 cases while in the Army and found that exostosis was quite common in this area and, in each case, the patient may not have had a bed sore at the time of the survey but gave a history of having had a bed sore in that area at one time or another. We took a biopsy of these and found that they were low grade osteomyelitis in each case.

About the bladder control he mentioned, with repeated enemas every two or three days, we did find in the Army that that worked very well following the pattern of the gastric reflex.

With regard to drugs and opiates, many cardotomies have been done because patients were not studied thoroughly, their drug addiction causing them to think they had pain, and I heartily agree with him that drugs should be withheld.

I would like to ask a question. What are his criteria on amputations? I would hate to think that amputations were going to be an easy way out. We should be very careful. That started in the second World War; and unless you have had a lot of experience, I do not think you should make that decision. Dr. Street is in a position to do it.

If we could carry home just one thing, I wish all the men in this group would take home and preach the gospel that these cases are never hopeless. Also, if you yourself do not want to handle them, it is certainly excusable; but for heaven's sake, please transfer them or find somebody who will handle them.

Augustus Thorndike (Boston, Mass.): I would like to speak in commendation of Dr. Street's paper. My interest in the problem of the paraplegic was landed in my lap when I happened to be on General Kirk's staff. I remember distinctly the first patients that were sent home from Europe and the condition in which they arrived at Halloran Hospi-

tal. The striking features then were the malnutrition and drug addiction. I think Dr. Street has done a wonderful thing to present the paper with these axioms so well set apart. They are axioms, and have produced the results that he described.

I would like to ask him one question. I would like to ask him how many deaths he has had in that series of 600 patients.

DANA M. STREET (closing): Fractures occasionally occur, but more commonly in getting in and out of automobiles, shutting the door on one's leg and similar accidents rather than in falls when the patients are actually weight-bearing and ambulatory.

In treating fractures the newer forms of internal fixation have been a godsend. One patient was treated for three months in skin traction and an ulcer up and down both sides of his leg plus delayed union developed. He was then treated with medullary nailing, and union was prompt. He was able to be turned frequently, and the ulcers healed rapidly.

For the supracondylar fractures of the femur, Rush's double pin method has been of great help. The patients do well in spite of the fact that some of them do not ambulate.

I have had no experience with the particular solution referred to by Dr. Kuhn. We have used zepharin in some cases.

With regard to resecting the ischial tuberosities, we resect them down to the obturator foramen, which is quite an appreciable amount. One difficulty we encounter then is that ulcers develop on the posterior aspect of their greater trochanters, because of the increased pressure in this area.

We have seen some myositis ossificans in these patients, even though they may not have had a previous ulcer and no apparent road for infection.

As to the criteria for amputation, if a patient has solidly ankylosed hips, is unable to get up in a wheelchair, is confined to his bed, has been resistant to treatment in the form of a Jones' type of pseudarthrosis or other pseudarthroses, and the ankylosis has recurred several times, then we go ahead and amputate. Also, if he has hip joint infection, associated with ulcers which have been resistant to closure and is, again, confined to his bed, we amputate.

Dr. Jostes brought up a point which seems very pertinent to me. If a veteran can get this treatment —and there are about 80,000 paraplegics in the country at the present time—and a civilian cannot get it, what about socialized medicine? It is certainly a strong talking point.

DR. KELLOGG SPEED: What about the mortality?

DR. STREET: I should have added that I am not in favor of socialized medicine.

As to mortality, we have had about forty deaths, not all attributable to the condition. There were about six automobile accidents that resulted in death and various infections, but the majority were urinary tract infections.

AUGUSTUS THORNDIKE (closing): In presenting this series I trust that experience will be gained throughout the country in the limb-fitting industry, so that the civilian surgeons will find this prosthesis a satisfactory solution for many of their problems of above-knee amputees.

BLOOD AND PLASMA VOLUME STUDIES IN THE SEVERELY INJURED

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CARE of the injured has been of paramount importance throughout the entire history of medicine. In projected visions of the future there is no reason to believe that the surgery of trauma will attain anything but increasing importance. In the treatment of those sustaining severe injuries one must think in terms of the patient as a whole rather than limiting his attention to management of the injured part. Recent studies have served to reemphasize the importance of maintaining fluid balance and circulating blood volume in the management of such emergencies.

Hurley Hospital is situated in an industrial area and approximately 10,000 individuals come to the emergency room annually. Many of these have been severely injured and their care constitutes one of the major services of the hospital. In recent years the tendency toward immediate definitive care of these injuries has increased. This has made evident the frequent inadequacy of the more common laboratory procedures such as blood cell counts, hemoglobin determinations, hematocrit calculations and the concentrations of protein or chlorides in estimating the status of the internal state. Therefore, an effort has been made to determine whether the coordination of blood and plasma volume determinations with the usual laboratory procedures would give a more accurate appreciation of the patient's condition.

One of the more common sources of error in evaluating the injured patient is the degree of hydration. For example, normal plasma sodium, chloride or protein concentration may be found in states of dehydration when actually there is a marked total deficit.[1,2,10]

Hematocrit values demonstrate a relatively wide range of normal. Griffin, Abbott and their group reported hematocrit values in fifty-nine apparently normal male subjects as ranging from 41.8 to 52.4.[18]

In 1945 this same group demonstrated the inconsistencies of hematocrit, plasma proteins, as well as other commonly used tests in the treatment and in the prognosis of thermal burns.[3] It has been shown that hemodilution is present early in second degree burns and may give evidence of a "false" anemia.[16] Still another variable as presented by the burn case is the predominant loss of plasma from the second degree burn, which leads to later dehydration and hypoproteinemia, as opposed to the depletion of red cell mass in the third degree burn. Hemorrhagic and other forms of traumatic shock present similar variables in hemoconcentration.

Another difficulty encountered in the handling of severely injured patients is the lag between the trauma and the appearance of recognizable signs of the shock state. The body's ability to compensate is the basic controlling factor in the delay of onset of shock. It has been said that the body does not automatically compensate for a blood loss greater than 750 cc.[5] However, the rate of blood loss as well as the patient's condition prior to injury frequently alters this. In response to any shock-producing stimulus afferent impulses arising in the area of injury reflexly produce an intense and prolonged activity in the sympathetic nervous system.[28] This role of reflex vasoconstriction in the maintenance of blood pressure in the immediate post-traumatic period is generally recognized.

In the face of these variables in the body's response to trauma it has seemed that determination of the blood volume as an additional measurement of the status of the fluid compartments would offer a significant advantage.

Methods for measuring blood volume of intact animals or man have been successively introduced over the past six or seven decades. These have included measurement of blood dilution after large intravenous infusions, methods for measuring plasma volume from the dilution of slowly diffusible foreign substances such as foreign proteins, vital dyes, gum acacia and hemoglobin, as well as methods for measuring total erythrocyte volume by the carbon

monoxide, radioactive iron and the radioactive phosphorus technics.[4,9,19–21,23,26]

From a practical standpoint the procedure of choice today, and the one we have been using, is that resulting from the extensive research of Gregersen.[6,16,17] A sample of blood is taken and a known amount of the blue dye T-1824 is injected intravenously.[13,25] Ten minutes later a second sample is taken from the opposite arm or from the femoral vein. In some cases of severe shock when there has been a question of delayed circulating time or the so-called "pooling of blood," a later sample has been taken at fifteen minutes. To date, in these cases we have rarely noted a significant difference in result. When some variance is found, it is advisable to use the second value.[17] The plasma from these samples serve as control and unknown and are compared colorimetrically with a standard. From these figures can be calculated the plasma volume, and in this series of cases we utilized the hematocrit in determining the total blood volume. As correlaries to this we determined, on the same samples of blood, the specific gravities of both the blood and the plasma, the plasma protein and the hemoglobin as well as the hematocrit. In some instances, in following the course of the illness, the plasma and urinary chlorides were measured to aid in deciding upon the indicated infusions.

There are admittedly several defects in the application of these methods. In the first place there are several sources for technical error in the procedure. Most of these are relatively obvious and when encountered will necessitate discard of the results and repetition of the test. Usually these involve hemolysis of red cells resulting from the use of a tourniquet or in mishandling of the blood samples. Failure to inject the entire dye sample within the blood stream will of course give erroneous determinations. These difficulties can, however, be surmounted by carefulness and honesty in the performance of the procedure.

Of greater significance is the fact that blood volume in normal individuals may vary significantly. Gibson and Evans[15] reported that the blood volumes in ninety normal individuals varied as much as 30 per cent from the average, although two-thirds of these were within a 10 per cent variance. Age, sex and physical measurements have been utilized in establishment of standards, but none represent absolute values for all persons. The body weight has been found to be the most convenient standard, but even that must be evaluated carefully, especially when the patient is either obese or malnourished. We have thought that although calculations of surface area of the body have not contributed to additional accuracy in this problem, perhaps a factor such as body specific gravity or volume displacement in either air or water would be of value. To date we have had no opportunity to put this experimental problem in progress.

The more recent reports concerning measurement of red cell mass with P32 tagged cells have cast further doubts on the accuracy of the dye method, in which it is necessary to use the hematocrit value to calculate the total blood volume.[28] However, in defense of results obtained in this study it may be pointed out that the differences in total blood volume determinations by the two methods is quite consistent. Therefore, it would seem that a group of determinations done by either procedure would have significance.

Inasmuch as the primary motivation for this report is to indicate a practical use for this method, several illustrative cases have been chosen for presentation.

The first is that of a twenty-four year old girl who was involved in an airplane crash in August, 1949. On admission to the emergency room she was in a most profound and obvious state of shock. She had sustained a severe head injury with a basilar fracture, many facial fractures, chest injury with rib fractures and a tension pneumothorax, pelvic fractures, fracture of the left femur, extensive comminution of the distal tibia, fibula and tarsal bones bilaterally with accompanying severe soft tissue damage and loss of a large fragment of the left tibia.

Intravenous infusions were started immediately and during the first twenty-four hours she received a total of 3,000 cc. whole blood, 750 cc. plasma, 2,000 cc. 5 per cent glucose in distilled water and 1,000 cc. 5 per cent glucose in normal saline. At the end of forty-eight hours she was still unconscious and oliguric. In an attempt to aid in planning the next phase of treatment volume studies were done. (Table 1.)

From these figures it can be seen that although the total blood volume was still significantly depressed (29 per cent), the plasma volume itself was near the expected normal. Therefore, the important deficit was in red cell mass. Further calculations revealed a probable total deficit of 377 gm. of hemoglobin which would require 2,400 cc. whole blood to replace. These figures were

assumed to be rather accurate indications of the patient's status.

She was given a transfusion of 2,000 cc. whole blood over a period of three days and the determinations repeated. (Table II.)

TABLE I

Body weight	50 kg.
Specific gravity	
blood	1.044
plasma	1.020
Hematocrit	31 per cent
Hemoglobin	10.6 gm. per cent
Plasma protein	4.95 gm. per cent
Expected blood volume	4,000 cc.
Determined	2,642 cc. (29 per cent deficit)
Expected plasma volume	2,150 cc.
Determined	1,963 cc. (8 per cent deficit)

TABLE II

Specific gravity	
blood	1.057
plasma	1.022
Hematocrit	47 per cent
Hemoglobin	15.8 gm. per cent
Plasma protein	5.5 gm. per cent
Determined blood volume	3,842 cc.
Determined plasma volume	2,075 cc.

Each of these values was within normal limits. During this period the patient received daily, by gavage, adequate calories and protein. This is considered important from the standpoint of preventing the body from utilizing the blood solely for its caloric and nutritional value. It would seem that this principle would be demonstrated to its greatest advantage in replacement of blood volume deficit in the debilitated or in those with the so-called chronic shock.[9]

The second case was a fifty-eight year old woman who was involved in an automobile accident sustaining bilateral comminuted supracondylar femoral fractures. These were not amenable to surgery and she was placed in skeletal traction. On admission there was no alteration in pulse or blood pressure and no signs or symptoms suggesting shock.

TABLE III

Body weight	76.2 kg.
Specific gravity	
blood	1.052
plasma	1.026
Hematocrit	37 per cent
Hemoglobin	12.5 gm. per cent
Plasma protein	6.2 gm. per cent
Expected blood volume	6,103 cc.
Determined	3,718 cc. (30 per cent deficit)
Expected plasma volume	3,231 cc.
Determined	2,380 cc. (26 per cent deficit)

Initial blood volume studies revealed the significant findings recorded in Table III.

She received 1,000 cc. whole blood in two days. Volume studies were repeated and a significant deficit was found to have persisted. Of blood, 1,500 cc. were then given over a three-day period and determinations repeated. (Table IV.)

TABLE IV

Specific gravity	
blood	1.052
plasma	1.023
Hematocrit	39 per cent
Hemoglobin	14.5 gm. per cent
Plasma protein	5.9 gm. per cent
Determined blood volume	6.263 cc.
Determined plasma volume	3,821 cc.

It is to be noted that it required the initial estimate of approximately 2,500 cc. whole blood to bring the values to normal. Repeated studies during her convalescence demonstrated maintenance of these values.

The next situation is that of two women involved in the same automobile accident and without evidence of circulatory collapse on admission to the emergency room. E. S., age forty-six years, sustained fractures of the left femur at two levels and a supracondylar fracture of the right femur which extended into the knee joint, as well as a dislocation of the left elbow. W. W., age fifty-two years, sustained a single fracture of the left femur. In both cases open reduction of these fractures was decided upon. It was contemplated that E. S. should be operated upon first and blood was obtained to be given during the procedure. Comparative determinations are listed in Table V.

On the basis of body weight this meant a blood loss of 3,450 cc. in the patient with three femoral fractures and 1,267 cc. in the patient with the single femoral fracture. Furthermore, it is evident that neither the clinical appearance on admission nor the other laboratory procedures listed gave any indication of this difference in the two patients.

While the significance of the volume studies was being considered, E. S., with the multiple fractures, began to demonstrate the onset of shock with an increasing pulse rate, and a rapid drop in blood pressure to a level of 60/40.

Whole blood transfusion was begun and this patient's operation was delayed for three hours. After W. W. had been operated upon, E. S. was taken to the operating room, blood was continued and her surgery accomplished without untoward event.

It has been interesting to note that in patients sustaining fracture of the femoral shaft a most consistent blood loss has been found, usually amounting to between 800 to 1,200 cc. for each fracture. We have recently been told of some unpublished work of Clay Ray Murray in which he demonstrated, by the method of weighing sponges, that

approximately 1,000 cc. blood was usually lost in the region of a femoral fracture.[11]

In fractures of the tibia and fibula the blood loss has been found to be much more variable. Usually these have shown relatively insignificant loss. However, we have done volume determinations on very few of these individuals.

These determinations have also demonstrated value in cases of patients with intra-abdominal bleeding. One was a forty-one year old factory worker who was struck in the abdomen by a rapidly revolving wheel about 2 feet in diameter. On admission he had clinical signs and symptoms of shock. A fracture dislocation of the lumbar spine, L4 on 5, was present. The abdomen was rigid and exquisitely tender. Hemorrhage had occurred into the recti muscles. It seemed clinically that some intra-abdominal viscus had been injured; however, at surgery the significant finding was a very extensive retroperitoneal hemorrhage. The value of the blood and plasma volume determinations in this case was the prompt and accurate demonstration of the magnitude of blood loss. (Table VI.)

Table V

	E. S.	W. W.
Body weight	75 kg.	65 kg.
Specific gravity		
blood	1.052	1.051
plasma	1.026	1.022
Hematocrit	37 per cent	38 per cent
Hemoglobin	11 gm. per cent	13 gm. per cent
Plasma protein	6.5 gm. per cent	5.6 gm. per cent
Expected blood volume	6,000 cc.	5,200 cc.
Determined	2,550 cc. (57.5 per cent deficit)	3,933 cc. (24 per cent deficit)
Expected plasma volume	3,375 cc.	2,925 cc.
Determined	1,607 cc. (52.4 per cent deficit)	2,439 cc. (16 per cent deficit)

Table VI

Body weight	56 kg.
Specific gravity	
blood	1.043
plasma	1.022
Hematocrit	37 per cent
Hemoglobin	12 gm. per cent
Plasma protein	5.5 gm. per cent
Expected blood volume	4,760 cc.
Determined	1,658 cc. (65 per cent deficit)
Expected plasma volume	2,520 cc.
Determined	1,045 cc. (58 per cent deficit)

The last case to be presented was a sixty year old man who was struck by an automobile, sustaining fractures of the proximal one-third of the left radius and ulna, and comminuted fractures of the left tibia and fibula. Open reduction and internal fixation was done on the forearm and the lower extremity was treated with traction. Initial blood volume determinations revealed no significant abnormality. (Table VIII.) Postoperatively the patient caused some concern because of his poor appetite. On the sixteenth postoperative day he vomited. A fecal impaction was discovered and relieved. Neither the vomitus nor the feces appeared to contain blood. He was then asymptomatic, and three weeks post-trauma the lower extremity was encased in plaster and he was allowed in a wheelchair. This was not well tolerated. He complained of weakness, became quite faint and the skin pallor was marked. A blood volume determination was done and the significant deficit noted. (Table VIII.) On the basis of an old history of duodenal ulcer treatment was instituted for bleeding ulcer. The following day he vomited dark blood and passed a black, tarry stool per rectum. Of whole blood, 3,000 cc. were given intravenously over a period of forty-eight hours. The patient's condition remained poor and the blood pressure could be kept above shock levels

Table VII

Body weight	80 kg.
Specific gravity	
blood	1.048
plasma	1.021
Hematocrit	32 per cent
Hemoglobin	10.2 gm. per cent
Plasma protein	5 gm. per cent
Expected blood volume	6,800 cc.
Determined	6,054 cc. (10 per cent deficit)
Expected plasma volume	3,600 cc.
Determined	3,025 cc. (15 per cent deficit)

Table VIII

Specific gravity	
blood	1.034
plasma	1.022
Hematocrit	20 per cent
Hemoglobin	5.4 gm. per cent
Plasma protein	5.5 gm. per cent
Expected blood volume	6,800 cc.
Determined	3,831 cc. (43.6 per cent deficit)
Expected plasma volume	3,600 cc.
Determined	3,065 cc. (14.8 per cent deficit)

only by constant blood transfusion. Therefore, he was operated upon and the bleeding was found to be caused by two large ulcers on the lesser curvature of the stomach. The duodenal ulcer appeared to be healed. Gastrectomy was done and the patient recovered.

The laboratory determinations for the blood and plasma were then easily brought within normal limits and maintained throughout convalescence.

CONCLUSION

The general impression appears to be that the blood and plasma volume determinations have merit in research centers but are not suitable for the ordinary clinical laboratory.

We have attempted to correlate these determinations with the more commonly used laboratory procedures in order to gain a clearer understanding of the true status of fluid balance and circulating blood volume in the severely injured.

Cases are presented to illustrate that the method can be used to give valuable information in the treatment of these individuals.

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STUDIES OF BLOOD VOLUME IN PATIENTS DEPLETED AS A RESULT OF TRAUMA*

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THIS report is concerned with the study of changes in blood volume in the patient who has lost weight as a result of trauma. Decreased blood volume, increased interstitial fluid volume, weight loss and a susceptibility to shock with minor operative trauma was noted in 1943 by Lyons[1] in a group of soldiers depleted as a result of trauma and infection. Studies of blood volume have subsequently been carried out on several hundred depleted patients, many of whom have been previously reported.[2,3] The syndrome originally noted by Lyons was labeled by the conveniently descriptive term "chronic shock." Principal results of previous studies are the following: (1) Patients who had lost weight from many disease states including malignancy, infection, inadequate protein intake due to organic and functional states, and others, consistently showed diminution in blood volume due to both red cell and plasma volume deficits. (2) Hemoglobin concentration was an inadequate index of total red cell volume or total hemoglobin deficits in the depleted patient. (3) Standard blood volume was proportional to optimal rather than actual weight. (4) Correction of red cell volume deficits preoperatively and replacement of operative and postoperative blood loss by transfusions resulted in elimination of shock and in early convalescence and weight gain.

METHOD

Plasma volume was measured by the T-1824 blue dye method under fasting, resting conditions, and blood was drawn without tourniquet compression. The hematocrit was measured by centrifugation in Wintrobe tubes at 2,500 r.p.m. for thirty minutes and hemoglobin gms. per cent, as oxyhemoglobin, spectrophotometrically. Machine standardization for hemoglobin gm. per cent was checked at intervals against the $CuSO_4$ specific gravity method and against a Van Slyke standardized machine. Plasma volume, total circulating red cell volume, total circulating hemoglobin, blood volume and total circulating plasma protein were calculated from the aforementioned measurements. In all cases the patient's optimal weight was determined from a careful history by one of us.

RESULTS

A total of twenty-six sets of determinations was done on fifteen unselected patients who had lost weight as a result of a variety of traumatic states. For comparative purposes two patients who had not lost weight but who were subjects of trauma are also included. Table 1 summarizes essential results in these patients. No patient illustrated in Table 1 had received blood for a period of over three months prior to blood volume determinations. Ages in this group varied between nineteen and seventy-five years. From Table 1 the following observations may be made:

1. Extreme variability of weight reduction occurred; the amount of weight loss correlated roughly with the duration and extent of injury. Although significant correlation between the amount of weight loss and total red cell volume was not apparent in this series, such correlation in serial determinations on the same patient has previously been noted.[3] No reciprocal relationship between the extent of weight loss, duration of illness and hemoglobin concentration or plasma volume was noted in this series. It is doubtful that E. L. (No. 4) had lost 25 pounds in one month; more likely he was below his optimal weight at the time of injury.

2. The hemoglobin concentration in this group with weight loss as measured by the hematocrit was not significantly reduced and in over half exceeded 44 per cent. Reciprocal

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relationship between hematocrit and plasma volume and between hematocrit and total circulating red cell volume is compared. (Fig. 1.) The normal ratio in a patient with anemia but no weight loss or decrease in plasma volume is illustrated by J. S. (Fig. 1.) It will be noted that marked discrepancy between hematocrit and total red cell volume exists in the other patients, all of whom had sustained weight loss.

3. Plasma volume as related to standard for optimal weight varied from 69 per cent to 95 per cent. It was reduced in all patients except No. 17 who had sustained no weight loss. The plasma volume did not relate to the total red cell volume except that both were reduced in the patients with weight loss.

4. Total circulating red cell volume varied from 55 per cent to 97 per cent of standard for optimal weight; thus red cell volume deficits of from 75 ml. to 1,508 ml. occurred in this group. Only patient No. 16 who had lost no weight had a total red cell surplus. Patients No. 14 and 7, who had insignificant deficits, had healed their wounds and were gaining weight. Most significant red cell deficits were in patients sick or disabled for over one month. Normal blood, 500 ml., contains approximately

TABLE 1

No.	Name	Weight Loss (lbs.)	Diagnosis and Duration	Hematocrit (%)	Plasma Volume (% of Standard)	Red Cell Volume in ml. (% of Standard)	Red Cell Volume Deficit in ml.	Blood Volume in ml. (%)
1	O. C.	10	Ununited fracture tibia, disabled 10 mos.	45	3,750 (82)	3,070 (73)	−1,130	6,820 (77)
2	J. G.	28	Monoplegia following fracture of spine and femur, 18 mos.	44	2,450 (94)	1,649 (69)	− 750	4,099 (82)
3	J. K.	5	Compound fracture tibia with osteomyelitis, 4 mos.	50	3,255 (83)	3,255 (93)	− 255	6,510 (86)
4	E. L.	25	Severe facial injury, 1 mo.	39	3,095 (94)	1,978 (71)	− 820	5,073 (83)
5	R. A.	8	Fracture hip, 4 mos.	42	1,992 (81)	1,439 (67)	− 860	3,431 (75)
6	C. D.	12	Fracture hip and pelvis, 1 mo.	54	2,551 (69)	2,194 (92)	− 860	5,545 (79)
7	R. D. R.	8	Fracture tibia healed (gaining and ambulatory), 5 mos.	45	3,109 (94)	2,725 (97)	− 75	5,834 (96)
8	G. T.	5	Traumatic paraplegia, 2 years Amebiasis, 3 mos. previously	40	3,525 (95)	2,350 (72)	− 900	5,875 (84)
9	H. R.	5	Fracture humerus, 3 wks.	47	3,097 (86)	2,746 (87)	− 404	5,843 (86)
10	R. M.	30	Compound fracture with osteomyelitis, 2½ mos.	35	3,421 (91)	1,842 (55)	−1,508	5,263 (74)
11	V. L. G.	3	Compound fracture tibia and fibula, 10 das.	40	2,906 (88)	1,937 (69)	− 863	4,843 (79)
12	A. P.	12	Severe crushing of hand and infection, 2 wks.	47	3,356 (91)	2,976 (92)	− 274	6,332 (91)
13	P. L.	9	Hand injuries, severe with infection, 9 mos.	45	2,428 (90)	1,986 (80)	− 484	4,414 (85)
14	L. H.	5	30 per cent burn, healed, 2 mos.	47	2,606 (95)	2,311 (92)	− 144	4,917 (93)
15	F. S.	8	Compound fracture of tibia with delayed union, 8 mos.	48	3,000 (83)	2,770 (88)	− 380	5,770 (85)
16	V. W.	0	20 per cent burn, 4 das.	53	2,217 (76)	2,702 (100)	05	4,919 (86)
17	J. S.	0	Minor foot injury and Buerger's disease, 2 wks.	42	2,760 (106)	1,998 (83)	− 402	4,758 (95)

225 ml. of red blood cells. Thus patient No. 1 would require 2,500 ml. of whole blood for restoration of his red cell volume to normal.

5. Blood volume in this group was diminished in all, varying from 74 per cent (No. 10) to 96 per cent (No. 7) of standard for optimal weight. In four patients only (Nos. 7, 12, 14 and 17) was blood volume over 90 per cent of standard. The wounds of patients No. 7 and 14 had healed, and the latter were gaining weight at the time of determination. Patient No. 17 had not lost weight. Patient No. 12 had been injured for two weeks. Direct relationship between amount of weight lost and the blood volume was not noted. In Case 17, without weight loss, reduced blood volume was due to red cell volume decrease only.

Hemoglobin concentration in gm. per cent and total circulating hemoglobin was measured also in this series. They correlated closely with the hematocrit and total red cell volume, respectively. Plasma protein concentration and total circulating plasma protein did not vary significantly from standard for optimal weight.

A group of ten patients employed in industry and subject to the usual hazards of trauma was also reviewed. These had all lost weight due to a variety of disease states including complicated peptic ulcer, alcoholism with malnutrition and bronchiectasis, but had continued to work. All had appreciable blood volume deficits due to decrease in both the red cell volume and plasma volume fractions. Most had relatively normal measures of hemoglobin concentration. Figure 2 illustrates these findings in three cases.

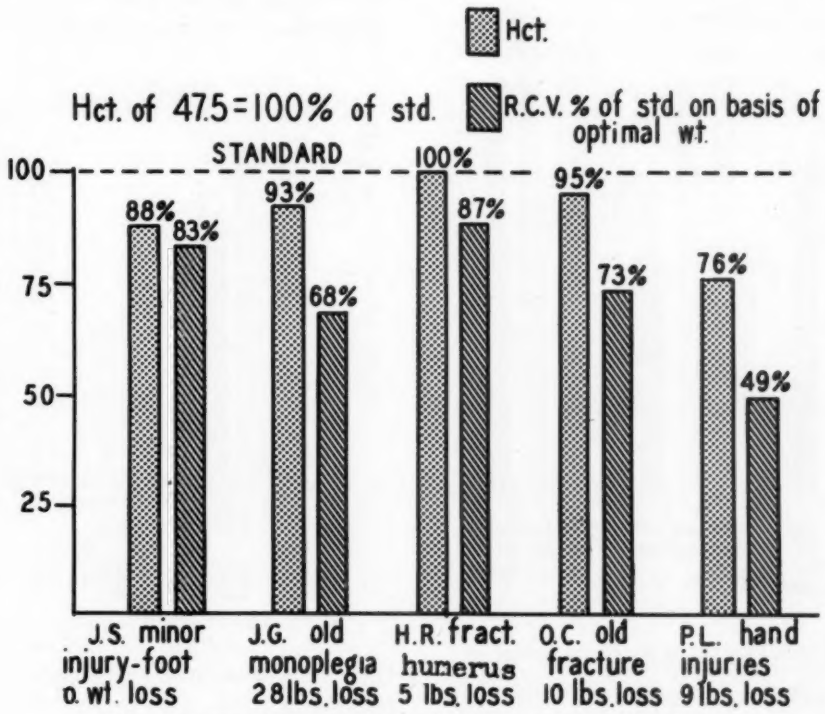

FIG. 1. Comparison of hematocrit with total red cell volume.

Serial determinations after administration of blood and surgical intervention were done on patients No. 1, 13, 14 and 8. Patient No. 1 (Fig. 3) with an ununited fracture of the tibia had his measured red cell deficit corrected by 1,000 ml. transfusions on the two days preceding surgery. Surgical blood loss estimated at less than 500 ml. was replaced on the day following surgery in this patient. Measurements two days after surgery show a red cell volume of standard (98 per cent) for optimal weight and a plasma volume still below standard (79 per cent). One month later his measured red cell volume was being maintained at standard for optimal weight (101 per cent) and his plasma volume was increased (85 per cent). His weight at this time was still below standard.

Patient No. 8 (Fig. 4) also had approximate quantitative correction of his measured deficit in the immediate preoperative period and had

replacement of estimated operative blood loss at the time of surgery. Three and a half months later his red cell volume was near standard for his optimal weight (95 per cent) and his plasma volume was approaching standard (90 per cent). No systolic or diastolic blood pressure

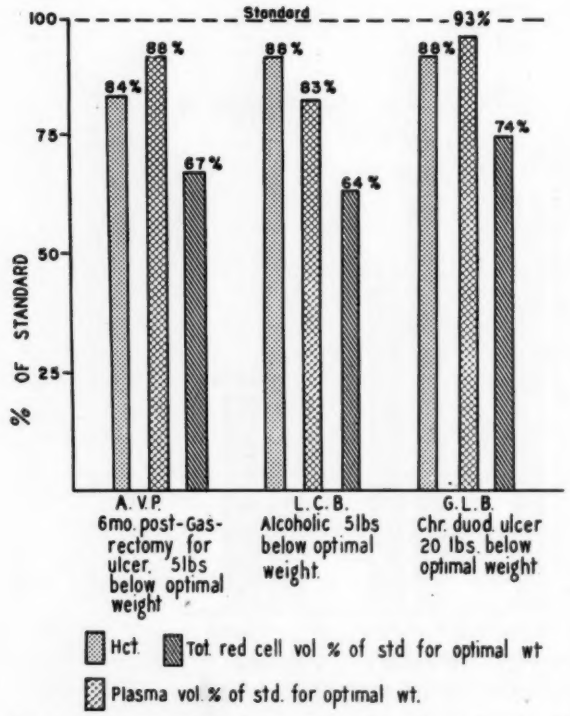

FIG. 2. Hematocrit, plasma volume and total red cell volume in depleted patients exposed to industrial hazard.

drop was noted in this patient at the time of spinal anesthesia induction nor at the time of section of either sympathetic trunk. Three determinations were done at monthly intervals on patient No. 14, who had severe 20 per cent burns of the legs complicated by persistent severe infection. A progressive decrease in red cell volume from 90 per cent to 77 per cent of standard for optimal weight, along with a weight loss of 17 pounds was noted. This decrease occurred in spite of the administration of five units of blood and a high protein intake. During this time his plasma volume remained at or above standard. Measurement two months after control of infection showed cell volume and plasma volume to have regained standard levels without subsequent transfusion therapy. His weight had increased 20 pounds, but he was still 11 pounds below his optimal weight.

As illustrated in Figure 5, P. L. (No. 13), one month after severe bilateral hand injuries with replacement of estimated blood loss, had a high plasma volume (115 per cent) and a decrease in red cell volume. The deficit was partially corrected by 1,000 ml. of blood.

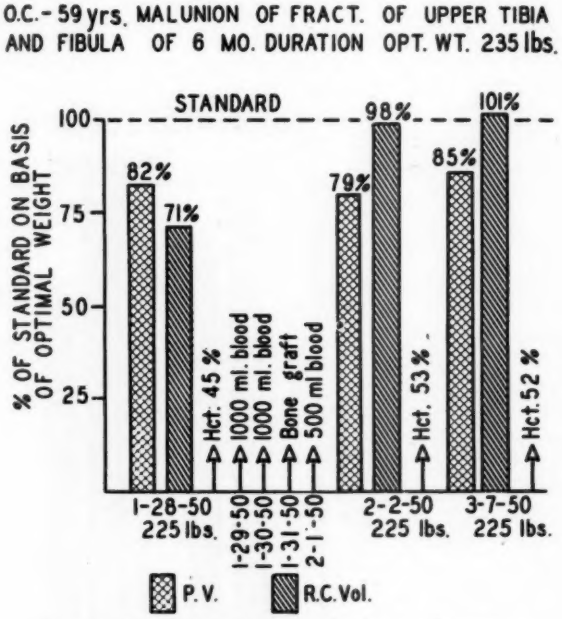

FIG. 3. The effect of quantitative replacement.

Infection persisted although further weight reduction did not occur. Five and a half months later measurement showed severe depletion of both plasma volume (76 per cent of standard) and red cell volume (49 per cent). Repeated determination after 2,000 cc. blood showed a little less than quantitative replacement. Measurement four months after elimination of infection by sequestrectomy showed a plasma volume of 84 per cent of standard and a red cell volume approaching standard (92 per cent). He had also nearly regained his optimal weight and was working in a light occupation.

COMMENTS

As illustrated by the cases studied in this series the loss of weight from causes secondary to trauma results in the clinical syndrome previously designated as "chronic shock." Characteristic of this syndrome is a significant decrease of plasma, red cell and total blood volume. Because of low plasma volume, such decrease is not indicated by measures of hemoglobin concentration. In fact the hematocrit and hemoglobin gm. per cent were within

normal limits in most of these cases. Therefore, measurement of the blood volume is necessary to ascertain blood deficits and transfusion requirements. The T-1824 blue dye method measures with clinical accuracy deviations from standard determined by the same method, and

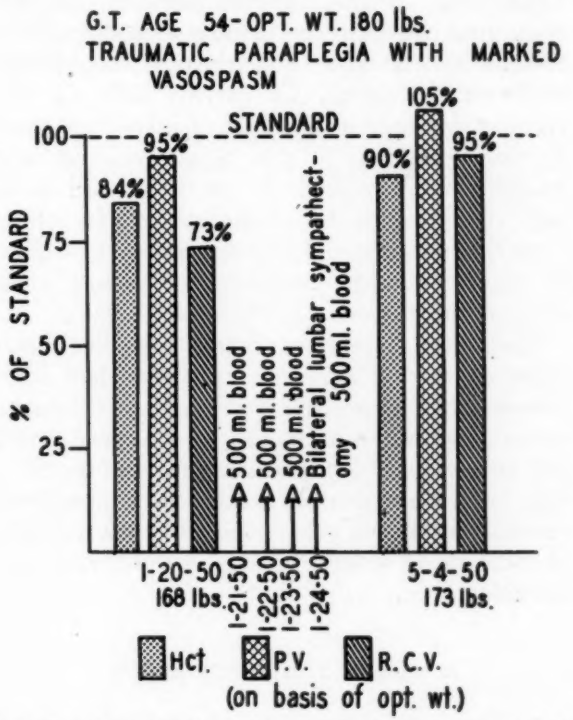

FIG. 4. Quantitative replacement and maintenance at standard for optimal weight postoperatively.

we believe its use is clearly indicated in the depleted group. In the non-depleted patient measures of hemoglobin concentration accurately depict the total amounts of circulating hemoglobin or volume of red cells, and blood volume measurements should be unnecessary. In event of recent blood loss a lag period for hemodilution exists. During this period blood volume determinations may be of more value than serial measurements of hemoglobin concentration in assessing transfusion requirements.

Individuals who have lost weight from a variety of disease states are not infrequently employed in industry and exposed to occupational hazards. As illustrated in Figure 2 such individuals have a low plasma, cellular and blood volume and have thus a chronically constricted vascular reservoir. Blood loss from trauma in individuals so physiologically altered rapidly leads to severe shock because of their inability to compensate by further vasoconstriction for such loss. For the determination of blood requirements blood volume measurements are therefore particularly indicated in such individuals even after minor trauma. From a prophylactic standpoint in industrial medicine the frequent measurement of body

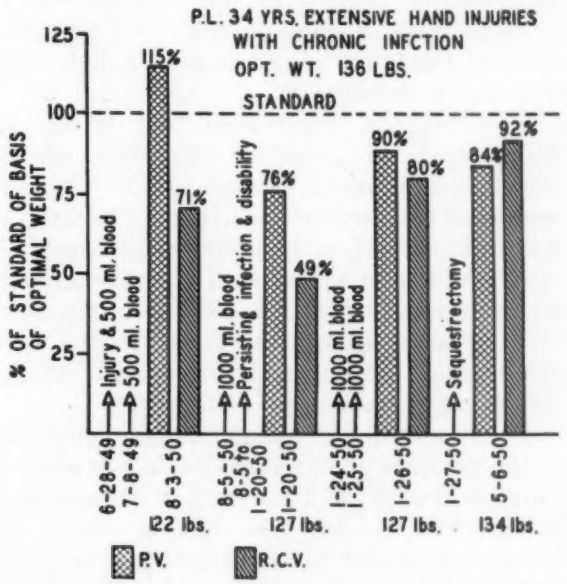

FIG. 5. Effect of persistent infection and inactivity on the blood volume.

weight, investigation of workers with weight loss and the elimination of those with protein depletion from hazardous occupation would appear to be a sound policy.

The development of a state of chronic shock in a traumatized previously healthy patient depends upon a number of factors including: inactivity, unreplaced blood loss, inadequate protein and caloric intake, infection and exudative protein loss. Bed rest alone results in a depletion of the blood volume affecting both fluid and cellular portions and averaging 500 ml. in a three-week period.[4] Depletion of hemoglobin results in the preferential use of protein for the manufacture of hemoglobin and thus in protein depletion and weight loss.[5] It is often difficult to get the uncomfortable, lonesome, hospitalized individual to ingest enough protein to correct his hemoglobin deficits and to maintain his tissue proteins and heal his wounds. In the patient with infection, as illustrated by L. H. (No. 14), who had persistent infection in third degree burns, large amounts of blood failed to maintain total circulating hemoglobin near standard, even though he also received large amounts

of protein. The maintenance of the patient with intractable infection is one of the most difficult in the field of traumatic surgery, not only because of exudative and metabolic loss of protein, but also because of the associated depression of protein (including hemoglobin) metabolism. Success in the management of such patients depends on early and definitive surgical treatment of infection as well as upon restorative therapy.

It should be emphasized that blood can supply but a negligible proportion of the debilitated patient's protein needs. The correction of total red cell deficits does lead to the establishment of early positive nitrogen balance[6] and makes subsequently administered or ingested protein available for the formation of body proteins other than hemoglobin. More rapid wound healing and restoration of weight and strength results.

The syndrome of "chronic shock" developed in the patients of this series within as short a time as ten days. Thus in any traumatized patient who has had time to lose weight the hematocrit cannot be depended upon to measure total red cell deficits. More profound deficits, particularly in plasma volume, occurred in patients who had been sick for periods longer than a month. This supports the theory that the decreased plasma volume is related to tissue protein depletion. The amount of weight loss in this or previous series did not correlate with the plasma volume decrease, however, suggesting that other factors besides the tissue protein may be of importance in producing the chronic shock syndrome. Weight loss may be due to loss of substances other than protein, particularly of fat and water. Fat as well as carbohydrate has a protein-sparing action.[7] Such a sparing mechanism may come into play after loss of a certain amount of body protein. The only exceptions to plasma volume decrease in this group occurred in patients who had received recent blood, namely, patient L. H. (No. 14) and P. L. (No. 13). These two had weight loss and had important red cell volume deficits. Thus sparing of protein for body protein synthesis instead of hemoglobin synthesis should not have been a factor in their high plasma volumes. We cannot explain the high plasma volume in these cases. An open field awaits further investigation of the mechanism of fluid interchange as it relates to metabolic alteration in the depleted patient.

We have attempted to restore and maintain normal circulating blood volume in the traumatized patient by means of repeated blood transfusions. In the non-depleted patient blood needs have been based upon serial measures of hemoglobin concentration and estimates of blood loss. In the depleted patient who has sustained injury we believe blood volume measurements and quantitative volumetric replacement should be carried out. In the patient depleted as a result of injury we have routinely measured the blood volume and quantitatively corrected the measured total red cell deficits by transfusions. In those requiring surgery such correction has been done in the immediate preoperative period at a rate of 500 to 1,000 cc. whole blood daily.

Estimated operative blood loss has been replaced during surgery. Emphasis has been placed, in the postoperative or convalescent period, upon maintenance of standard total red cell volume by transfusions and upon a high caloric and protein intake. Such a regimen results not only in prevention of shock but also in more rapid wound healing, weight gain and convalescence.

SUMMARY AND CONCLUSIONS

1. The establishment and maintenance of standard total red cell and blood volume for optimal weight protects the patient depleted as a result of trauma from shock and hastens his wound-healing and convalescence.

2. Measurement of plasma, red cell volume and blood volume deficits is essential in the depleted patient because the hemoglobin concentration measures in such a patient do not depict total amounts of hemoglobin. The T-1824 blue dye method measures with clinical accuracy deviations from standard blood volumes similarly determined.

3. Establishment of normal red cell and blood volume does not eliminate the need for subsequent adequate protein administration nor the need for early definitive surgical treatment of infection.

4. The individual who has lost weight from a variety of disease states is easily precipitated into shock from minor blood loss and should be protected from industrial hazard.

5. Factors contributing to the development of a state of "chronic shock" are discussed.

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THE SO-CALLED "BLOOD SUBSTITUTES"*

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TO those interested in the broader aspects of trauma few problems are of greater importance than the replacement of the elements of the blood lost following injury. The prevention and treatment of shock, whether caused by hemorrhage, burn or other severe tissue damage, depend chiefly on the early return to the circulation of those elements of the blood that have been lost or destroyed. The proper healing of damaged tissues during the weeks following injury also demands replacement of those elements of the blood lost gradually through the wound. The dynamic equilibrium[1] between the body proteins and plasma proteins requires that a normal plasma protein volume be maintained before the body proteins will be adequate for tissue repair. If the building materials sufficient to maintain normal hemoglobin and plasma protein volumes cannot be taken by mouth and assimilated, they must be given parenterally. Thus in the surgery of trauma the replacement of blood loss in a broad sense is of paramount concern.

WHOLE BLOOD, FLUID WITHOUT A SUBSTITUTE

The term blood substitute is a misnomer. The so-called substitutes may maintain the circulating volume, but they cannot assume the oxygen-carrying function of the blood. When the blood volume has been seriously depleted by trauma, the initial problem may of necessity be to restore the blood volume with substitutes which tend to remain in circulation; eventually, however, the oxygen-carrying ability of the blood must be revived and this requires replacement of lost red blood cells.

That whole blood is the only entirely effective replacement following severe trauma was repeatedly noted during World War II. At the beginning of the war it was naively hoped that plasma might indeed prove to be a complete substitute. However, this hope was quickly dispelled by combat experience. Churchill,[2] after extensive experience with the wounded in the Mediterranean Theatre, stated: "Plasma alone is not adequate to prepare a seriously wounded casualty to withstand the surgical procedures that are essential, or to carry him through the critical postoperative period. Plasma is a substitute for whole blood only in the sense that it can be packaged and stored in adequate quantities in areas where blood cannot be obtained. Plasma is not a substitute for whole blood in the physiological sense."

Even though the circulating volume is maintained after trauma, failure to supply certain viscera with sufficient oxygen leads to an irreversible state of shock, after which the further administration of substitutes or even blood itself will not save the patient. The recent experiments of Fine and his collaborators[3] on irreversible shock may partially explain the need to maintain the oxygen-carrying power of the blood. They observed that irreversible shock from hemorrhage could be prevented in dogs by perfusing the liver with well oxygenated blood even though the arterial blood pressure and the blood volume were kept at a level identical with the control animals which died. Well oxygenated blood perfused through the jugular vein did not prevent death. It seems likely that the liver is the "trigger organ" in the production of irreversible shock following injury and that prevention of prolonged liver anoxia is vital. After severe injuries this usually requires whole blood.

The recent reports of Evans[4] and Abbott[5] emphasized that large volumes of whole blood must be given to patients with burns. This is true not only during the later stages of burn anemia but also during the period immediately following the burn, when shock is most apt to occur. According to Moyer[6] whole blood is lost in burns from hemolysis and capillary stasis. In experimental burns in dogs Moyer found that defibrinated whole blood was much more effective in preventing death than plasma or other substitutes.[7]

By giving whole blood soon after the burn occurs shock is more effectively prevented and chronic anemia of the late stages is obviated.

If, then, whole blood is the best fluid re-

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placement following trauma, why is it pertinent to consider substitutes? Chiefly, for two reasons, namely, (1) because whole blood can at present be preserved only for relatively short periods, it is impossible to build stockpiles sufficient for a national emergency. The present blood procurement program is scarcely able to meet the needs of civilian hospitals in peacetime. In a national emergency, unless better methods of preserving blood have been developed, substitutes must be used as alternative therapy. (2) In some injuries the loss of red cells may be less than the loss of certain other fractions of the blood. In these instances it is not only more economical but also safer to replace only the substances lost. To increase the number of red cells above normal might overload the circulation. In the stages of tissue repair following injury the plasma proteins may be more depleted than the red blood cells. In such instances it may be best to give plasma alone.

In still other instances when the red blood cells have been more depleted than the plasma, it may be advantageous to infuse suspensions of red blood cells separated from the plasma. Suspensions of red cells supply the elements most concerned with oxygen transport, while not adding greatly to the osmotic pressure of the blood. They are thus especially useful in patients with anemia in whom there is unusual danger of overloading the circulation as, for example, patients with heart disease. Methods of preserving the red cells for long periods are being actively studied by several groups of investigators.[8] Hamilton,[9] in our department, has been able to preserve the red blood cells of dogs for as long as eighty-one days by segregation at low temperatures and resuspension of cells in suitable media.

The fluids that have been used when whole blood is not available or when it is desirable to supply especially depleted fractions of blood may be divided into the following two groups: blood derivatives and plasma substitutes.

BLOOD DERIVATIVES

The two blood derivatives that have found general use as substitutes for whole blood are plasma and albumin.

Plasma. This blood derivative was used extensively in World War II. Before the war methods had been perfected for the preservation of plasma by drying it from a frozen state. Thus prepared and packaged the labile components were preserved. Plasma can perform all the functions of whole blood except those of the red blood cells. The functions of plasma are maintenance and stabilization of the plasma volume, transport of hormones between tissues, transport and mobilization of antibodies, protection against blood loss by components of the clotting mechanism, transport of lipids and other substances closely associated with the plasma proteins and nutritive functions of the plasma proteins.

Tremendous quantities of plasma were used during the war for the immediate treatment of shock from injury, for burns and to supply proteins when an adequate amount could not be taken by mouth. Plasma saved many lives during the war. It must be reiterated, however, that plasma is only an expedient and is not a complete substitute for whole blood in the treatment of shock due to hemorrhage or severe trauma. It must not be used to the exclusion of whole blood in the immediate treatment of burns.

The protein needs, at least of the experimental animal, can be supplied effectively by giving plasma intravenously. Whipple et al.[1] found that weight equilibrium and normal health could be maintained in dogs for at least three months with intravenous plasma as the sole source of protein, as long as the necessary carbohydrates, fats, salts and vitamins were given by mouth. The cost of the method is excessive and this will probably prevent its use in man.

The most serious complication from the use of plasma has been homologous serum jaundice. Because the dried plasma has been prepared from pools, consisting usually of eight donors, the virus of homologous serum jaundice has been spread much more widely by plasma than by whole blood. Follow-up studies of patients who have received pooled plasma have shown that the incidence of homologous serum jaundice is about 5 per cent.[10,11]

Figure 1 shows the liver of a patient who received pooled plasma on our service in 1946, because of a blood pressure fall following cholecystectomy. He was readmitted sixty days later, severely jaundiced, and died of liver failure within five days. At postmortem examination almost no viable liver cells could be discovered. Since that time we have not used

FIG. 1. Photomicrograph of liver of patient who died from homologous serum jaundice; no viable liver cells are noted.

pooled plasma unless it has been treated to destroy the virus. Except in dire emergencies plasma from pools of more than two donors must not be given unless the virus has been destroyed.

Methods are urgently being sought which will destroy the hepatitis-producing virus in blood and blood derivatives without seriously affecting their useful properties. The following four methods have been proposed: heat, ultraviolet radiation, x-rays and cathode rays and the addition of chemical reagents.

Of great promise are the reports of Hartman and his co-workers[12] at the Henry Ford Hospital. They observed that one of the nitrogen mustards, methyl-bisamine hydrochloride (HN_2), has effective viracidal and bactericidal effects in the presence of either plasma, serum or whole blood and that the end effects of the added nitrogen mustards are non-toxic if the pH of the system is not too low. Red blood cells, complement, immune bodies, phosphatase, and fibrinogen were reported to be affected only slightly by effective doses of HN_2. The prothrombin time, however, was greatly prolonged.

While the use of nitrogen mustards is still in the experimental stage, ultraviolet irradiation has been reported to be an effective and practical method of freeing plasma from the hepatitis-producing virus. Levinson and co-workers[13] have reported the administration of over 5,000 doses of irradiated human plasma to patients with no ill effects and no evidence to indicate that the procedure does not destroy the virus. Abelson,[14] working with human volunteers, found that in seven of fifteen controls hepatitis developed when they were given serum containing the virus, while in none of eleven volunteers receiving irradiated serum did hepatitis develop. At the Hospital of the University of Pennsylvania we have just begun to use irradiated plasma for routine use. Methods by which whole blood can be effectively irradiated have not yet been reported. In fact this may not be possible.

Of the two remaining methods proposed for sterilization heat has been used for serum albumin and will be discussed later; x-rays and cathode rays are still in the experimental stage. If these methods for sterilization prove practical and effective on a large scale, large stores of purified plasma should be built up for emergency use.

Albumin. During World War II human serum albumin was produced in purified form from the fractionation of plasma and used chiefly as a substitute for whole blood in the treatment of shock.[8,15] The albumin molecule is large enough to be held in the blood and yet small enough to have a high osmotic potency. One hundred ml. of 25 per cent normal human serum albumin is osmotically equivalent to 500 ml. of citrated plasma. Thus it combines the advantages of a small volume with high osmotic efficiency. It is stable and can be dispensed in an aqueous solution. It has, therefore, several advantages over dried plasma: it can be administered immediately without having to be dissolved and it does not require a solute for shipping. Any of the solutions for parenteral use may be employed in any desired concentration. A 5 per cent solution of albumin in saline is equivalent to 500 ml. of plasma and can be substituted for plasma in the treatment of burns. Originally, albumin was supplied dissolved in twice isotonic sodium chloride solution containing a mercurial bacteriostatic agent. Its use for the treatment of cirrhosis of the liver with ascites and for the nephrotic syndrome led to the development of salt poor solutions without a mercurial. The new standard albumin solution is 25 per cent albumin at a pH of 6.8 with a low sodium content, with no mercurial agent, and with ten hours of heating at

60°C. to destroy the virus of homologous serum jaundice.

The intolerance of the body to salt during the first twenty-four to forty-eight hours after surgery has been emphasized by Coller,[16] and it is likely that types of trauma other than surgery also produce salt intolerance. A solution of albumin with a low salt content should be more acceptable for use in trauma than the old solution. An exception might be burns, however, in which large amounts of extracellular sodium are lost and must be replaced.

Because of the high osmotic efficiency of albumin, care must be taken not to overload the circulation and produce pulmonary edema. Overloading is much more apt to occur when albumin is given for liver cirrhosis and for the nephrotic syndrome, but is possible even after trauma.

PLASMA SUBSTITUTES

Because of the great difficulties noted before in building up stockpiles of whole blood and blood derivatives for a national emergency, the development of a safe and efficient plasma substitute is needed. The two most promising substances that have been proposed as plasma substitutes are gelatin and dextran.

Gelatin. During the years 1942 to 1945 an intensive experimental and clinical study of gelatin was made in our department by Koop and his associates.[17–21] Ossein gelatin prepared as a 4 or 6 per cent solution was found to be both safe and effective when given intravenously for the treatment of the early stages of traumatic shock. This gelatin, prepared from the long bones of cattle, is composed of relatively long molecular chains which are not excreted by the kidney as rapidly as shorter molecular gelatin. It remains in the blood stream from three to five days. No significant damage to vital organs has been noted either in animals or in humans. Heuper[22] reported that in dogs large quantities of gelatin impaired the production of plasma proteins and hemoglobin, and produced degenerative and proliferative arterial lesions of the sclerosing type. When given in amounts comparable to those which would be given to humans for the treatment of trauma, gelatin was found to be innocuous in experimental animals.[23] Careful pathologic studies in human beings have failed to show significant tissue damage from gelatin infusions. Six per cent gelatin solution has twice the osmotic pressure of plasma and accordingly must be given with great care to patients with cardiac damage. The maximum blood volume increase occurs about three hours after the infusion.

Difficulty with blood typing and crossing is encountered after infusions of many of the macromolecular solutions that have been used as plasma substitutes. The cause is pseudo-agglutination, and it is noted after infusions of gelatin. For this reason it is advisable to take a blood sample for typing and crossing before the plasma substitutes are given. If no samples have been obtained, however, the addition of 1 per cent glycine solution to the serum mixture has been found to prevent pseudo-agglutination.[24]

Practical advantages of gelatin are its availability, low cost and freedom from reactions. The disadvantages of gelatin are (1) it is probably not metabolized by the body and (2) it is in the physical state of a gel at low temperatures and runs slowly through intravenous equipment. The first disadvantage is a minor one, because the chief purpose of a plasma substitute is the emergency treatment of shock or impending shock. Whether the infused solution supplies calories is of no real importance. The second disadvantage is real and one that we found to limit its use greatly under battle conditions in Burma during 1943 and 1944, especially during the winter months. The gelatin can be kept liquid by storing it at more than 50°C. or by heating the bottle before use. In the emergencies in which a plasma substitute is most needed, however, heating may be impossible.

Gelatin solutions that remain in a liquid state at low temperatures have been produced, but they consist of smaller molecular particles that are rapidly lost from the circulation and thus do not exert the same efficiency in the treatment of shock.

Dextran. Dextran was first discovered in Germany as a mucoid material formed during the extraction of sugar from beets.[25,26] Found only in those sugar solutions infected with the bacterium, leukonostic mesenteroides, it is a polysaccharide built from glucose molecules by this organism. For use as a plasma substitute dextran is hydrolyzed so that its particles attain a range of molecular sizes close to that of the plasma proteins, about 100,000. The smaller dextran molecules (from 50,000 to 60,000) are excreted rapidly through the kidneys, but the

larger ones are retained longer in the blood stream, disappearing only after four days. Following infusions of dextran the sedimentation rate is increased but it returns to normal within a few days.

Dextran has been used extensively in Sweden during the last few years with the results reported as excellent. Thorsen[27] reports the use of 20,000 units given to 5,000 patients and states that it is an effective plasma substitute, that is non-injurious to tissues, locally and systemically. He states that it is used routinely at his hospital to prevent shock in major operations, and that the hospital transfusion services in Sweden rely to a large extent on dextran for emergency cases.

Animal studies in this country have shown that when given in amounts comparable to those which would be used in humans, dextran is not harmful to tissues.[28] All reports of the use of dextran have not been favorable. In 1946 a group of thirty patients at the Presbyterian Hospital in New York City were given dextran intravenously with severe anaphylactic or anaphylactoid reactions in one-third of them.[29] Because of the freedom from reaction reported by others, it appears probable that the solutions used by the Presbyterian Hospital contained impurities.

Dextran is now being studied at the Hospital of the University of Pennsylvania.[30] To date thirty patients have been given dextran with only one reaction (a mild chill and fever), and with clinical responses that indicate it is an effective plasma substitute. Dextran has been especially valuable on the labor floor and in the receiving ward for the emergency treatment of hemorrhage while whole blood is being obtained. Whether dextran will prove to be of such value that large stockpiles should be manufactured depends on the results of further study, but reports to date are encouraging.

SUMMARY

1. There are no substitutes for whole blood. The so-called blood substitutes may maintain blood volume but do not replace the oxygen-carrying capacity of blood. Oxygenation of the tissues is vital following trauma and anoxia leads to irreversible shock—possibly initiated through damage to the liver.

2. The blood derivatives, plasma and albumin, are useful in the management of trauma, especially in emergencies while whole blood is being procured and when the plasma volume has been more depleted than the red cell volume. Because of the danger of homologous serum jaundice, pooled plasma must never be given unless it has been freed of virus. At present, ultraviolet irradiation is the most practical and efficient means of sterilization.

3. Effective plasma substitutes are needed because it now appears impossible to build stockpiles of blood and blood derivatives sufficient to meet a national emergency. Of the plasma substitutes now advocated, gelatin and dextran are the most promising.

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DISCUSSION OF PAPERS BY DRS. DODDS AND CURRY, NELSON AND LINDEM, AND RAVDIN AND FITTS

R. Arnold Griswold, (Louisville, Ky.): The papers presented by Drs. Dodds and Nelson are on an extremely important subject. Whether the dye that is being used at present will be the final answer, I am not sure. Many physiologists object to this particular method because they believe that it is not accurate enough. This lack of accuracy may be a hindrance in strictly scientific laboratory work. However, the two papers this morning have shown that it is sufficiently accurate for clinical work.

I should like to emphasize that even with these laboratory methods we should not forget our clinical examination of or our clinical impression of the patient. You have all had interns and residents, I am sure, tell you that a patient was not in shock because he had a systolic pressure of 120; and yet, when you looked at him he was cold and clammy and you knew that he was in shock. This applies to one of the patients shown in the first paper, one of the two women in the same automobile accident. The one who had multiple fractures obviously had severe enough injury to produce shock, although her pulse and blood pressure were within normal limits on admission. Very shortly, as shown by the chemical studies, and verified by her clinical appearance, she was in shock. For this reason we should not forget to appraise these patients thoroughly while awaiting the laboratory reports.

The paper by Dr. Fitts re-emphasizes the fact that there are no adequate substitutes for whole blood. In this connection I should like to remind you that in hemorrhage into the serous cavities, autotransfusion is still a safe, feasible and practical method of putting blood into these patients while you are waiting for blood to come from a blood bank or waiting for typing and cross-matching in an emergency. Autotransfusion is safe if it is done within the first twenty-four hours following injury. After that period of time hemolysis is likely to make it dangerous; but when it is done a short time after the hemorrhage, it is a safe, feasible and practical method of restoring blood volume.

Charles G. Johnston (Detroit, Mich.): I want to reiterate what Dr. Griswold has said about blood

volume studies and their accuracy. I, too, have great doubts about the accuracy, especially the accuracy in relation to injuries, because there are a great many changes which take place that will cause differences in what you are measuring.

If it were just as simple as putting a batch of measured dye into a bucket of water, shaking it up and then taking a bit of the water and analyzing it to determine how much water was in that bucket, that would be all right; but we all know there are a great number of changes that take place in the blood stream in shock, not only locally but also generally.

Dr. Noer in our laboratories has been carrying on some studies with distention. Even slight amounts of distention cause great changes in the smaller vessels. The blood is held largely in large and small vessels. Great amounts of it are held in the smaller vessels which dilate and contract, and which leak blood out through the capillaries. Therefore, any measure of blood volume which takes in only a measure of the circulating volume will be quite variable and cause an inaccuracy if one is determining or trying to determine how much blood to replace. In this regard I think there is a tendency, with blood banks available, to give too much blood. Frequently, this is left to the anesthetist, and the anesthetist often will pour blood into patients who really need no blood replacement at the time, with the incident dangers which are associated with blood transfusion.

Blood transfusion is not an absolutely safe procedure because there are problems relating to some of the side groups which cause serious trouble, especially with massive transfusions, even if it is cross-matched well. I have seen patients who have been completely saturated with blood when they needed only a little bit, with continuous blood transfusion running in, because the operative procedure seemed to be one which was going to be quite heavy. The anesthetist thought he would get ahead of the surgeon and pour in plenty of blood. I think one must, therefore, be careful about that aspect as well.

Now, with regard to the blood substitutes, this has been a perennial problem. Dr. Fitts and his group have been studying it for a long time and they have shaken it down to one of simplicity; that is, a matter of getting something which we can put into a vessel which will keep the circulating volume up even though there is a limited amount of hemoglobin to keep the respiratory mechanism going. Nevertheless, it does keep the blood circulating around the vital structures, and it is important that we have this immediately, especially in cases in which there is not blood available and well cross-matched. It is important that we use a substitute that does not cause difficulties or harm; and while we have had no experience with dextran, we do know that the gelatin substance, from experience of others, does do very little harm and does give us a fairly good immediate restoration of volume. However, it must be replaced by blood at some time or other.

Whether one can put volume for volume back is, to me, still a moot problem. I do not believe it is possible to measure blood loss accurately enough to replace volume for volume, but Dr. Nelson's and Dr. Dodds' studies indicate that one can get a fair approximation from such studies, even though the possibilities of error are great.

MARTIN C. LINDEM (Salt Lake City, Utah): I am not going to make any apologies for blood volume determinations. If the proper indications for making them are carried out, the accuracy of the method cannot be contested. We could review Dr. Nelson's paper again and apply some of the proofs that we have, but I will direct my discussion to what Dr. Nelson has presented from our work and emphasize some of his points.

I should like to stress our belief that the T-1824 blue dye method of quantitative determination of blood constituents and calculating their deflection from standard is a dependable procedure. Let me emphasize that we calculate the deficiency from a similarly determined standard. We are not trying to calculate the actual amount of blood that should be in the circulatory system.

This laboratory procedure, carried out for an objective determination, has a very negligible coefficient of error. The dosage of blood needed for replacement is exactly measured; hence, guesswork about the amount of blood to be transfused is eliminated. Of hemoglobin 75 gm. are contained in 500 units of transfused blood; and on that basis, we calculate the hemoglobin deficiency and replace it volumetrically by that amount of blood bank blood.

The clinical observation has been made that when volumetric replacement of blood was done, no operative shock occurred in any one of our patients, although many of them were in very poor condition before they had been given a transfusion and brought back to the standard.

A question asked is, should blood volume studies be done preoperatively on all major surgical cases? The answer is definitely no. There is no more valid reason for doing routine blood volume tests on general surgical patients than there would be for doing routine liver function tests on all cases coming to the internist.

There is a specific indication based on clinical history of blood loss or nutritional deficiency. There is also an inherent morbidity in all laboratory tests. Venipunctures are painful; hematomas occur, as well as extravasation, when you puncture the vein; and a prolonged discoloration about the skin puncture may occur from a spillage of the dye.

Other studies previously published have shown that blood constituent depletion is a consequence of a variety of clinical and pathologic conditions. But

when trauma occurs on the ski slopes, (in this candidate for injury we would certainly expect no depleted individuals; however, they are there) on the highway or in the home, this selective indication pertains. That a thorough clinical evaluation must first precede the indication for blood volumetric determination is evident.

PHILLIP B. PRICE (Salt Lake City, Utah): It is significant that blood volume, which has long been largely of academic interest, has now come to have sufficient clinical interest for three papers in this conference to be devoted to it.

After having worked with the problem of blood volume measurements for many years and having preached the clinical importance of blood volume, I now find myself in the somewhat unfamiliar role of voicing a word of caution against any rule-of-thumb approach to the problem or any policy of blood replacement by formula.

We have the problem first of accurate measurement of blood volume. Even assuming that our methods are sufficiently accurate for clinical use, we cannot use the hematocrit without great caution in any indirect measurement of either plasma volume or cell volume. There is also the difficult problem of trying to measure blood deficits, since we do not know in any given case what normal blood volume is. We have the difficult problem also of proper blood replacement. The body is able to compensate to a certain extent; transfusions often have only transient effects; one must depend eventually on blood regeneration. Each of those factors needs to be assessed, but we have at present no good way of assessing them.

We need better laboratory methods to estimate blood deficits, and we need more reliable clinical criteria of adequate re-establishment of blood volume and adequate circulatory function.

CHARLES H. MAGUIRE (Louisville, Ky.): I certainly enjoyed all three of these beautifully done papers, but I think the point that Dr. Johnston brought up should be emphasized and stressed. That is the practice, because of our blood banks, of the wholesale use of blood by the anesthetist in order, as he mentioned, to "get ahead of the surgeon."

In our experience it does not take much blood, given during an operative procedure, to put the patient in a fairly critical condition. Too much blood over a short period of time brings on an acute pulmonary edema which, if it is not corrected, can be fatal.

Two practical things that should be used at the very first sign of pulmonary edema are the following: 100 per cent oxygen under positive pressure venesection. If you have given the patient too much blood, if he shows a little sign of pulmonary edema, take some of that blood away.

We have had several cases in which we realized shortly after surgery was complete that we had given the patient too much blood. They were given 100 per cent oxygen under pressure and as much as 1,000 cc. of blood removed. Those are two practical things that can be done if the anesthetist tries to stay too far ahead of the surgeon.

STEPHEN S. HUDACK (New York, N.Y.): I do not believe we should rest content with estimations of blood volume, because the volume of the blood, unless it is circulating, is physiologically unimportant. For that reason we have been working on a practical use for the ballistocardiograph so that we may know, from instant to instant, the cardiac output of a patient going through a severe surgical procedure.

Blood volumes, however, have been necessary in my experience in operating upon critically ill people who have been ill for a long time. In this way we have some idea of what their vascular tree is doing. I have found some individuals who, ill from a serious tumor lesion for months before being seen, may have a contraction of the vascular tree of 40 per cent. When serious surgical procedures are contemplated on an individual like that unless you know what the vascular tree has done and on what margin of safety you can operate, tread cautiously or you may be in trouble.

ALEXANDER VON LUTZKI (Berlin, Germany): I do not think there is much that can be added to what has been said, but I would like to emphasize the fact that thirty years ago traumatic surgery dealt chiefly with the mere sequelae of the injury itself. The traumatic surgeon considered chiefly the fractures, wounds and all those things that were destroyed in the normal anatomy. Today, traumatic surgery is far more physiologically minded, and in Germany we believe that this wonderful development is very much due to the efforts of American surgery.

I think it is correct to state that it is most important to maintain, keep up and restore not only the normal anatomy but also the normal physiology. That can be achieved in this country by many wonderful laboratory examinations which are possible because of the very complete technical equipment here, which we do not have in Germany or in most European countries. I believe it is fine when you are able to determine exactly what has to be replaced, and you can give the proper replacement on the basis of exact chemical and laboratory examinations. We must rely far more on clinical judgment and the clinical condition that the patient presents.

I think in almost all the cases that we see—and I think I am in agreement with the gentleman who emphasized this fact in the emergency cases—it is more important to see quickly what is the matter with the injured patient and to act quickly rather than to wait for a lot of checks.

There is one thing in particular which I should like to emphasize. We had one type of injury in

which I believe there was a strict contraindication to any blood or plasma transfusion. Let us take a man who fell down from a roof and had a blunt injury, for instance, of the abdomen, with no fractures and little or no blood loss. You see him first when he is brought into the hospital and notice he has a cold sweat on his forehead, his pulse is very strong and his blood pressure is elevated.

We think these are cases in which there is an irritation of the sympathetic nervous system, which plays an important role in this type of trauma, so that the vascular tree is contracted generally. Here it would be wrong to pump blood into the circulatory system, the capacity of which for the moment at least is narrowed. In such cases we wait and give the patient a rest. We give morphine or other sedative therapy, and wait until the irritation of the sympathetic nervous system is over and the vascular tree again widens. However, the patient may not recover from the reaction and passes into a state which we call collapse.

The first condition I described is what we call shock. When a collapse comes, we believe it is necessary to restore the circulating blood volume by giving a blood transfusion.

Woodrow Nelson (closing): I believe the inherent errors in the blue dye method are minimized by the use of basal conditions during the determination. For this reason, because basal conditions are not obtained in the immediate posthemorrhagic period, we have not used this method immediately following trauma.

With regard to the discussions of Drs. Maguire and Johnston, I think the best protection against overtransfusion in the depleted patient is blood volume measurement and volumetric replacement. We have had no difficulty with hydremia or with pulmonary edema in patients with quantitative correction preoperatively of measured hemoglobin deficits.

I should have defined the state of chronic shock, which was originally defined as a syndrome characterized by weight loss, decreased blood volume, increased interstitial fluid volume and increased susceptibility to shock, rectifiable by blood transfusion replacement. Why this state of affairs occurs, we are not sure. It has been hypothesized that it is on the basis of protein depletion and decreased elasticity of the interstitial tissue. Certainly, a fertile field awaits further investigation of better methods for determining blood volume and also further investigation of fluid interchange in the body.

Max E. Dodds (closing): I think that in a few words Dr. Griswold and Dr. Johnston have given a very fair representation of the method.

We have not by and large attempted to replace blood exactly volume for volume. Also, we have not replaced our total calculated deficits all at one time. We have replaced what we thought was necessary, repeated our determinations and attempted to correlate them in that fashion.

It has been surprising to us how quickly some patients, following acute trauma, have replaced or even formed excessive plasma volume. We believe that a complete replacement of calculated hemoglobin or total volume deficit, given over a short period of time, can very easily put the patient in pulmonary edema.

The one other point I want to mention is that regarding the calculated normal. We have used body weight simply because we have found no better corollary. That is probably one of the greatest sources of error in the method, not knowing the exact normal for various individuals. However, we have followed the suggestion offered by Gregersen. In the very debilitated and underweight, or in the very obese patients, rather than using their existing weight, take what would be considered a more normal weight for that individual. Consequently, the very obese person should not have the large calculated volume replaced, while in the very debilitated you may find that for the normal weight their volume deficit is much greater than that calculated for their existing weight.

William T. Fitts, Jr. (closing): Several of the discussers brought up the problem of giving too much blood and stated that the anesthesiologist often overloaded the circulation with whole blood at the operating table. For us this has not been a problem in routine major operations, but for operations of the magnitude of Whipple resections of the pancreas, portacaval shunts or extensive chest operations, in which up to 4,000 or 5,000 cc. of blood may be lost, it is a real problem.

In this regard some of the surgeons in our department have found it practical to use the dry sponge technic described by Dr. Gross of Boston: all sponges are weighed before operation and the blood loss estimated by calculating the increase in weight of the sponges discarded during operation. Blood can then be replaced as it is lost. Certainly, this method is not absolutely accurate, but our chest surgeons, who have used it extensively, believe that it is extremely helpful. Often, patients who have been given as much as 5,000 cc. of blood on the operating table are noted postoperatively to have blood volume determinations close to normal, blood replacement having been guided at operation by the dry sponge technic.

The problem of pseudo-agglutination was not discussed because of lack of time. Those of you who use gelatin or dextran should remember that they may produce pseudo-agglutination of red cells, which interferes with blood typing and crossing. A specimen for typing and crossing should be obobtained before such macromolecular solutions are injected.

FUNCTIONAL REPAIR OF THE MANDIBLE FOLLOWING BONE LOSS FROM INJURY, IRRADIATION NECROSIS OR TUMOR*

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THE restoration of the mandible for partial loss due to injury, irradiation necrosis or resection for tumor must follow several basic principles, the application of which will result in normal function and symmetrical contour. Sufficient time must be allowed for adequate healing following trauma, adequate removal of fibrous tissue and sclerosed bone must be accomplished, replacement of soft tissues with normal skin and subcutaneous fat for proper healing, and the choice of a graft that will unite primarily at the earliest possible time.[1]

When the mandible is being restored, in contradistinction to the repair of other bones, the lining to the mouth must be replaced when there is a complete loss of tissue. Unless the lining is replaced it is very difficult to return the fragments to normal position, so that pretraumatic occlusion and excursive motion of the jaw may be restored.

LOSS DUE TO TRAUMA

Battle casualties suffering from gunshot wounds of the lower jaw were treated in the forward hospitals by providing an airway, complete hemostasis, débridement and closure of the wound covering bone ends with soft tissue. Mucous membrane was sutured to skin when there was large soft tissue loss. No attempt was made to fix the posterior edentulous fragment as it was found that this could be brought down into normal position by muscle stripping at the time the bone graft was done.

Many patients had associated injuries of the upper face and maxilla caused by missiles entering the side of the face, crashing through the antral wall, traversing the palate and then destroying a large part of the mandible. Such wounds were treated by closure of the facial defect by direct suture or rotation flaps after débridement followed by a Caldwell Luc procedure, including a nasal antrostomy for drainage of the antrum, and closure of the incision. The palate was then closed, again with rotation flaps, and the mandibular fragments were immobilized with interdental ligation to prevent displacement.

Very few bone grafts to the mandible were done overseas in the general hospitals in the last year of the war since not sufficient time could be taken to allow the wound to heal properly for the reception of the graft. The greater percentage of defects requiring grafts healed without further drainage three to four months after the original injury.

Fifty-two gunshot wounds of the mandible requiring grafts for the restoration of function had bone loss of from a few centimeters to total loss.

The problem of immobilization of the fragments from gunshot wounds required many appliances ingeniously constructed, since the cases varied considerably depending on the teeth available in each fragment to receive the splint. The most common type of fixation used was the cast cap splint employed so successfully by the English dental surgeons.[2] These were constructed by taking impressions of the teeth in each fragment and reproducing them in caststone on which wax patterns were carved and cast with silver alloy. The models were assembled to occlude with the intact jaw so that when the individual fragments of the mandible were mobilized they could be held in their proper positions until healing of the graft had taken place. The castings were cemented to the teeth with black copper cement and immobilized to the intact maxilla by means of interdental wire ligation to a labial arch bar before surgery.

Iliac grafts were used in fifty-one cases and a rib graft in one. Endotracheal gas oxygen ether was used in forty-two cases, intubation being

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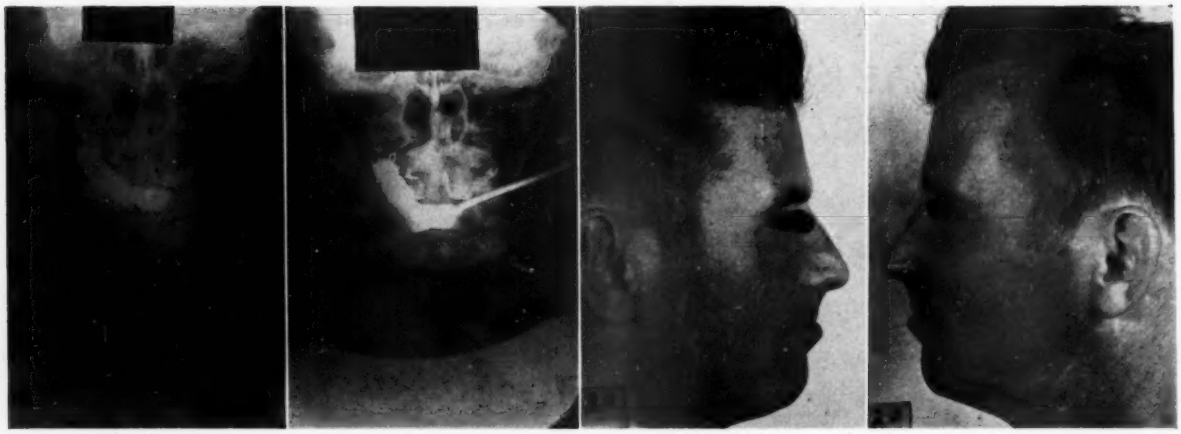


1A 1B 2A 2B

FIG. 1. Case 1. Gunshot wound with loss of mandible. A, x-ray showing defect in left horizontal ramus; B, post-operative x-ray showing bone graft in place and cap splint used for fixation.

FIG. 2. Case 1. A, scar of wound of entrance below right eye; B, scar of exit wound on left. Bone graft was healed at the time of the photographs.

done blindly. The remainder were done with novocain block and spinal anesthesia.

All cases healed per primam and only one required regrafting due to non-union. One was explored because of clinical non-union but required no further graft.[3]

Clinical union required from six to twelve weeks, after which normal masticatory surfaces were restored by the construction of partial dentures which were allowed to rest over the gone grafted areas, the stress being equally distributed between the teeth and soft tissues. The grafts withstood the pressure of mastication transmitted to them through the dentures without complication. The following case is typical:

CASE 1. Pvt. J. S. was wounded in Germany in 1945 when struck by a shell fragment. The missile entered his left face in the region of the right zygoma, passing through the right maxillary sinus and destroying the entire right side of the hard palate. (Fig. 2A.) It then destroyed the left horizontal ramus of the mandible making its exit through the left face and neck. (Fig. 2B.) He was treated in the aid station for shock and then transported to an Evacuation Hospital where the wound of the face was closed and the jaws immobilized. The palatal defect was too large to correct at that time. He was transferred to a General Hospital in the Zone of the Interior for further surgery. Approximately one year after sustaining injury an iliac bone graft was done to the left mandibular defect. (Fig. 1A and B.) This healed without complication and the palate was closed with an abdominal pedicle flap carried by the right arm. He was then transferred to another hospital where the pedicle flap in the palate was thinned and a denture constructed to replace the lost teeth.

LOSS DUE TO IRRADIATION NECROSIS

The effects of irradiation on the mandible, if the dose is sufficient, invariably results in necrosis of bone. This is due primarily to periostitis and sclerosing of the blood vessels and vascular spaces, resulting in ischemia and gangrene of the bone and surrounding tissue. Such changes seem to be particularly likely if for any reason teeth in the path of the rays are extracted following roentgen therapy. In many cases if the teeth have not been extracted prophylactically, they must be removed later because of the effects of the irradiation.

In the very acute stages of early necrosis following excessive irradiation, pain must be controlled and adequate drainage provided. After the acute symptoms have subsided sequestra are then removed as they are formed. In several of our cases, however, no definite sequestra developed, but copius drainage from devitalized bone and secondary oral infection continued for many months.

A number of patients were treated conservatively, that is, sequestrectomy and drainage until complete healing took place. This process is exceedingly long, invaliding the patient and interfering with his nutrition. It is also very difficult to tell the extent of the pathologic change caused by irradiation, as shown in the cases in which resection of the mandible was done only to find that within a few months necrosis appeared in the fragments and further resection had to be carried out.

3A 3B 4A 4B

FIG. 3. Case II. Irradiation necrosis of the mandible. A, x-ray appearance before resection; B, with bone graft in place.

FIG. 4. Case II. A, effects of irradiation on soft tissues of the right cheek; B, appearance after resection, bone graft and soft tissue replacement with cervicothoracic skin flap.

Since the mandible can be replaced quite satisfactorily, it is believed that radicle resection for irradiation necrosis may be indicated in some cases, particularly in the region of the ascending ramus, as soon as the acute symptoms have subsided. This procedure not only removes the cause of extending pathologic process due to slowly sclerosing blood vessels but also diminishes the period of invalidism.

If the dosage of irradiation is sufficient to damage the mandible, the surrounding soft tissue is also effected. There are the usual atrophic changes in the skin accompanied by fibrosis and sclerosis of blood vessels which may lead to necrosis of the skin and underlying structures.

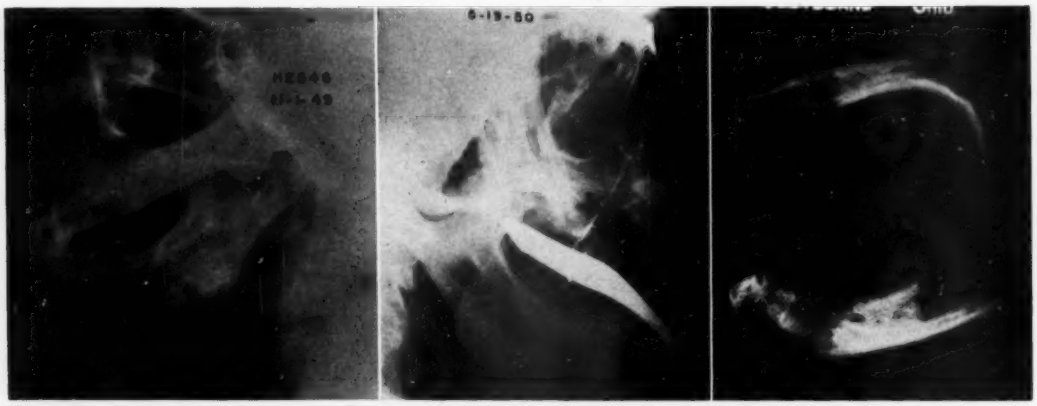
When the soft tissues are damaged to such an extent that healing is impaired, they must be replaced by normal skin, subcutaneous tissues and lining of the buccal cavity before the mandible is replaced in order to increase the speed of revascularization of the bone graft and give it normal covering. Replacement is also necessary so that the fragments will not be pulled out of position due to cicatrix, thus causing the malocclusion and inhibiting normal mastication. The lost tissue is best replaced with a cervicothoracic-lined pedicle flap brought up to the face in stages. Tissue for closure of the defect from the immediate vicinity cannot be used in most cases, because of the operator's inability to judge the extent of the effects of irradiation.

CASE II. A man, sixty years old, received x-ray and radium therapy to the right side of the face and jaw for squamous cell carcinoma of the alveolar ridge eight years before. Five years later he developed necrosis of the right mandible anterior to the angle which drained intraorally; subsequently he had three intraoral sequestrectomies. (Fig. 3A.) Two years ago the right horizontal ramus was resected (Fig. 3B), followed by replacement of the skin, subcutaneous tissue and lining of the buccal cavity by means of a cervicothoracic pedicle flap and bone graft. (Fig. 4A and B.)

The important factor in the restoration of the mandible following resection for any reason is to obtain the maximum contact of teeth of one jaw in relation to the other jaw in centric and all excursive movements. This problem becomes more difficult if not considered early in the planning of the treatment, and each plan should include the control of the fragments following resection.

Many methods have been used to retain the fragments in their normal position intended to counteract the pull of the muscles of mastication and the formation of cicatrix. The plaster head cap and wire combination applied to the angle of the mandible has been used for many years, but has a very limited value. Interdental ligation may occasionally be useful but the method also had disadvantages. Intramedullary fixation with a Kirschner wire, as advocated by Byars,[4] is probably one of the best because of its ease of insertion and the fact that it requires no previous preparation. The wire keeps the mandibular fragments in normal relation to each other, allowing some motion of the jaw. Care must be taken to prevent its erosion through the cortical plate due to pressure caused by the contracting scar and muscle pull. The wire is removed at the time the bone graft is done.

Various forms of prosthesis other than the Kirschner wire are useful for temporary retention of the fragments of the mandible and occasionally may be satisfactory permanently in lieu of bone graft. Tantalum plates of .015 to



5A 5B 5C

FIG. 5. Case III. Irradiation necrosis of the right horizontal ramus and symphysis. A, x-ray appearance before resection; B, after resection and insertion of tantalum plate; C, x-ray appearance of the resected bone (two views).

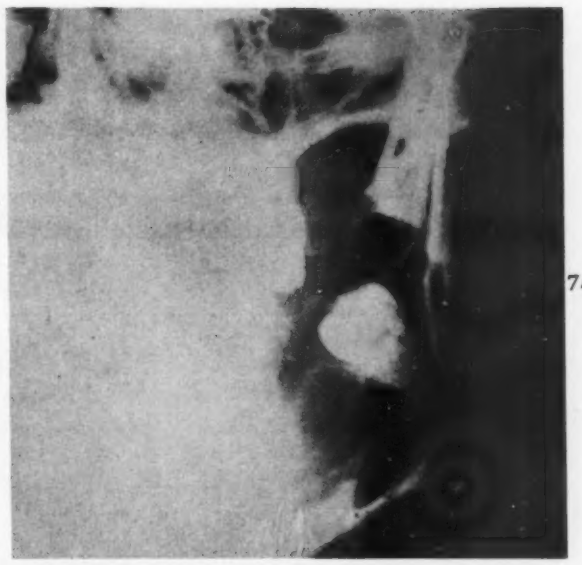
6A 6B 6C

FIG. 6. Case III. A, necrotic mandible exposed due to spontaneous slough of irradiated skin; B and C, appearance after resection and closure of the defect with cervicothoracic flap.

.020 gauge are easily fashioned at the time of operation with sterile tin snips or heavy scissors to fit the defect; the metal is well tolerated by the tissues. In some instances in which early bone graft seemed inadvisable following resection for tumor or irradiation necrosis resulting from the treatment of tumor, tantalum plates have been left in place for long periods of time. It seems possible that such substitutes may be satisfactory indefinitely, although our experience with the procedure is too short to justify such an assumption. The tantalum plate may be cut with pointed ends to impinge into the remaining fragments of mandible, or may be perforated and attached to the fragments by means of tantalum wire. The former method is preferable since with movements of the jaw the wires usually break or erode the bone eventually. If the plate is cut with too long a sharp point, the latter may gradually erode the bone end. Cases III and V illustrate the utility of the tantalum plate.

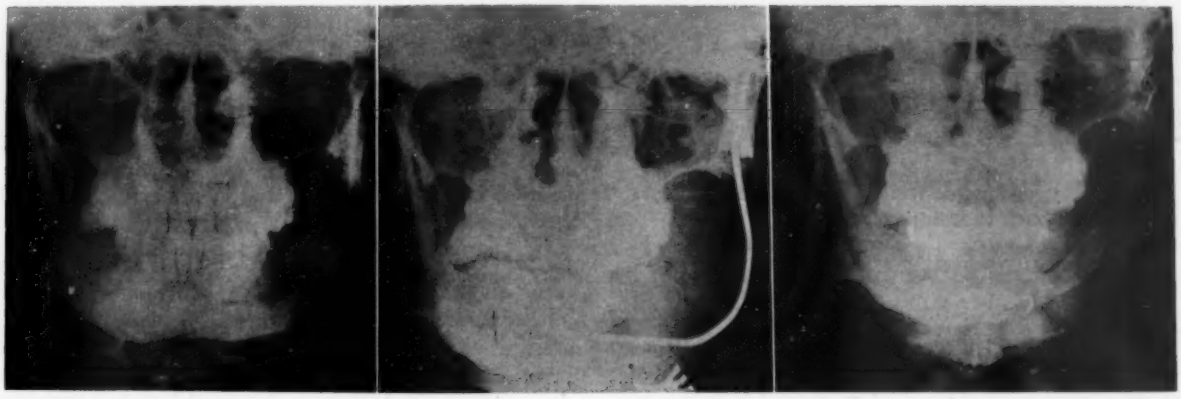
When irradiation necrosis occurs in elderly individuals, one is often inclined to accept less than a perfect functional result. Since such patients do not tolerate major resections well, it is probably justifiable to allow the dead bone to sequestrate and to remove it with minimal operative trauma. After the dead bone has been removed, the patient's age and poor physical status may render hazardous the soft tissue reconstruction required to make a bone graft practical. In a few such instances we have elected to leave the bone ends without internal fixation. When teeth are still present, it may be possible to construct a partial denture which maintains the position of the remaining mandibular fragments. More often the patient is already edentulous, however. A complete denture may be constructed which serves satisfac-

torily from a cosmetic standpoint, but rarely is stable enough to permit chewing. The elderly patient may, furthermore, have become so accustomed to his edentulous state that he prefers not to be bothered with either prosthesis or bone graft.



7A

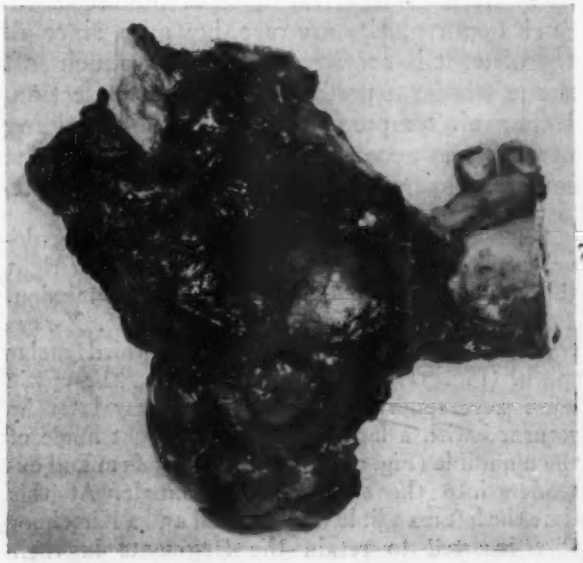
CASE III. A man of fifty-three presented radionecrosis of the horizontal ramus of the right mandible, resulting from radium treatment of squamous cell carcinoma of the floor of the mouth nine months prior to admission. The damage to the mandible had resulted from the cross fire effect of radium emanations placed in the floor of the mouth adjacent to the alveolar process and others placed within an involved lymph node in the submaxillary area. Skin overlying the horizontal ramus had sloughed exposing dead bone. (Figs. 5A and 6A.) A lined cervicothoracic skin flap was pre-



7B 7C 7D

FIG. 7. Case IV. Adamantinoma at angle of left mandible. A, before first resection; B, before second resection; C, after resection and fixation with Kirschner wire; D, after bone graft.
FIG. 7. E, the resected specimen in Case IV.

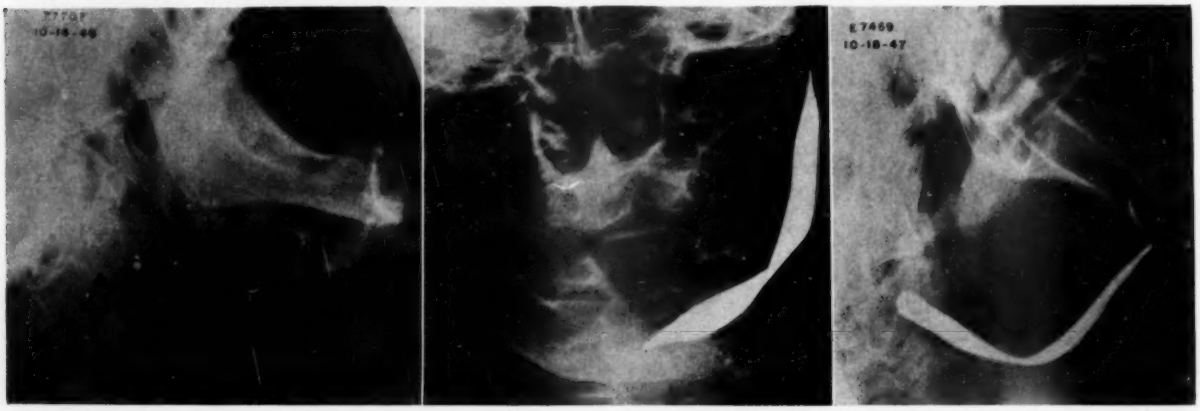
pared to close the buccal fistula. Three weeks later through an external incision the necrotic mandible was removed from the anterior margin of the vertical ramus to a point 2 cm. beyond the symphysis on the opposite side. (Fig. 5C.) A tantalum plate was placed immediately to maintain the remaining portions of the mandible in relatively normal position. At the same operation the cervicothoracic flap was set into the defect covering the tantalum plate. Four weeks later the pedicle was severed and returned to the neck. All operations on this patient were performed entirely with procaine (1 per cent) anesthesia. After nine months, due to further necrosis of the point of attachment of the plate to the vertical ramus, the latter was removed, trimmed and replaced. (Fig. 5B.) At the end of one year the functional result was satisfactory. Due to the extensive damage to soft tissue by irradiation, bone graft in this case would be difficult. (Fig. 6B and C.)



7E

8A 8B 8C

FIG. 8. Case IV. Photographs of the patient in Figure 7; A, cast cap splints in place before resection; B, appearance after resection; C, patient wearing a partial denture over the bone graft.



9A 9B 9C

FIG. 9. Case V. Adamantinoma of the mandible; A, appearance before resection; B and C, after resection and replacement with tantalum plate.

LOSS DUE TO RESECTION FOR TUMOR

The problem of bone replacement following resection of the mandible for tumor is similar to that presented by irradiation necrosis except that in the case of the unirradiated bone tumor there is less likely to be extensive soft tissue damage. When the bone tumor remains completely intrinsic, it may be possible to do a primary bone graft at the time of the resection. Such opportunities are rare, however, since all too often it is necessary to sacrifice much soft tissue in order to perform an adequate resection. Here again temporary fixation of the remaining mandible is necessary until circulation of the soft tissues is adequate to accept a bone graft.

CASE IV. A man, forty-five years of age, developed a swelling in the region of the lower right third molar tooth three years prior to admission. This was painless and did not fluctuate. X-rays revealed a cystic area around the third molar tooth. (Fig. 7A.) The third molar and the cystic mass were removed intraorally. A year later he returned with a larger mass at the right angle of the mandible (Fig. 7B) which was very firm and extended into the submaxillary triangle. At this time the left mandible was resected and a Kirschner wire inserted to retain the fragments in their normal position. (Fig. 7C and E.) Eight months later an iliac bone graft was performed (Fig. 7D.) The fragments were immobilized with cast cap splints which were cemented on the teeth and the jaws wired together before the bone graft was done. Six months after the bone graft a partial denture was constructed to replace the missing teeth in the region of the mandibular defect. (Fig. 8A, B and C.)

CASE V. A woman of fifty-seven presented an expanding tumor of the vertical and horizontal rami of the left mandible, which had been previously treated by external x-irradiation. The radiographic appearance was fairly typical of adamantinoma. (Fig. 9A.) The entire left mandible, except for the condyle, was resected together with attached muscles and buccal mucosa. A tantalum plate was inserted at the time of operation, impinging it distally into the symphysis and attaching it proximally to the condyle by tantalum wire. (Fig. 9B and C.) Because of the fact that the neoplasm had broken through the medial plate of the vertical ramus into the pterygoid muscles, the outlook was regarded as uncertain, and bone graft was accordingly delayed. At the end of two and one-half years there is no evidence of recurrence. Function remains satisfactory with the tantalum plate still in position, and the patient does not desire a bone graft. (Fig. 10.) Microscopic section of the tumor showed a moderately well differentiated

squamous cell carcinoma with stroma of the type commonly found in dental anlage tumors. It is believed the tumor was an adamantinoma the morphologic characteristics of which were altered by irradiation.

These cases illustrate two different methods of fixation of the mandibular fragments in preparation for a bone graft.

Since Ollier[5] in 1859 first established bone transplantation as a definite surgical procedure many substitutes have been used in place of autogenous bone due to the many theories advanced as to the fate of autogenous, homogenous and heterogenous bone grafts.

Bone from every available source has been utilized for the replacement of the mandible which bone ideally should be easily obtained and should provide enough cortical bone for stability in the larger defects and adequate cancellous bone (desirable for early vascularization as well as its ability to withstand infection and to be easily modeled). The bone found in the iliac crest fulfills all of these requirements. Iliac bone was not used with any frequency until early in World War II when Mowlem[6] began to use it in the form of chips for early replacement of gunshot wounds of the mandible. This type of graft was highly successful because it resisted infection. Mowlem observing these chip grafts by x-ray and histologic sections found that within eight weeks they developed their own cortical layer. He concluded that they retained their viability from the day that they were transplanted.

In a recent communication[7,8] the fate of autogenous iliac bone grafts was studied by determining the metabolic activity of the bone cells from the time of transplantation as a positive indication of viabiilty.

This was done experimentally by transplanting the ala of the iliac bone which had been cut into several equal pieces into the anterior chest wall of the dog. The animal was then given 200 microcuries of radioactive phosphorus (P^{32}) intravenously. The following day one of the grafts and a piece of the intact ilium were removed and ashed, weighed, and the amount of P^{32} calculated in each piece. The same procedure was carried out at various intervals until all the grafts were removed. It was found that fresh autogenous iliac bone grafts began to assimilate the isotope within twenty-four hours and that the rate of uptake gradually increased the longer the graft was left in the animal. The same was true of frozen autogenous bone grafts. The results were compared with boiled bone which was subjected to the same technic. The latter reacted by taking up P^{32} at a very low level, probably due to adsorption, and remained at this same level throughout the entire experiment, indicating inactivity of the bone cells. It was concluded that fresh iliac bone does retain its viability from the time of transplantation because of its early tissue fluid exchange and vascularization, as compared to that of boiled or dead bone.

10A 10B

FIG. 10. Case V. A and B, appearance of patient two and one-half years after resection for adamantinoma; tantalum plate still in place.

Bank bone or homogenous bone grafts have become popular because of their accessibility. We have tried this type of graft in two cases in which a segment of the bone was removed for benign tumor. In one case a rib which had been stored in a deep freeze was used to replace the symphysis of the mandible. Periodic x-rays showed that the entire graft disappeared in six months time. It was replaced, subsequently, with an autogenous iliac graft, with complete healing in twelve weeks. The second case developed osteoporosis with non-union at its anterior end but with clinical union posteriorly.

The fate of homogenous grafts is now being studied experimentally using the same technic as applied to the autogenous grafts but the results are not sufficient to report at this time.

CONCLUSIONS

1. Fifty-two autogenous bone grafts to the mandible for gunshot wounds of the lower jaw with one non-union are reported.

2. Satisfactory reconstruction of the mandible can best be accomplished by allowing complete healing to take place before grafting, having adequate normal tissue in which to place the graft for early vascularization, adequate fixation until bony union has taken place to insure normal occlusion of the teeth.

3. Radical resection of the irradiated necrosing mandible is advised in certain cases. All tissue effected by irradiation must be replaced with normal skin, subcutaneous fat and lining of the buccal cavity before bone grafting.

4. Mandibular fragments should be retained in their normal position with an intramedullary Kirschner wire or tantalum plate which are removed at the time of grafting. In certain cases the tantalum plate may be retained in lieu of bone grafting.

5. Autogenous immediate iliac bone grafts are the best type of graft to use in the reconstruction of the mandible since they probably retain their viability from the time of transplantation. Homogenous bone has a doubtful value in the raplacement of the mandible.

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DISCUSSION

Kellogg Speed (Chicago, Ill.): In support of this interesting discussion, I should like to cite a case of a woman, twenty-six years old,* who had disturbance in her teeth and swelling in her jaw. She consulted her dentist who x-rayed the jaw and then extracted three teeth, without making a diagnosis.

When she came to me, she had lost these teeth and had a swelling in the bone which, on examination of the film, was diagnosed as an infiltrating tumor extending from the angle of the jaw clear around beyond the symphysis to the opposite side. This tumor was diagnosed as potentially malignant. Before we did anything, we arranged with the dentist to make a dental impression of the teeth on the opposite side for the purpose of making a denture. Then an intra-oral resection of the involved portion of the mandible was performed. I would like to say that we first tied the external carotid artery, which I believe is one of the essential points in the technic of the operation.

The jaw was resected by means of a Gigli saw and the diseased portion removed completely, leaving the opposite side to be wired to the upper teeth. The mouth was irrigated and the patient was fed on a soft diet through that rather large opening. The diseased portion was an amorphous tumor, a myxoma of the bone, a malignant tumor of cartilaginous type.

Finally after five or six weeks the jaw space was opened extra-orally by incision through the cheek. Part of the seventh rib was taken and inserted through the external wound below the angle of the jaw and, without fixation, was placed in contact with both ends of the resected portion of the mandible. Five weeks later it had filled in quite well. Three and one-half months later it had grown in completely. A prosthetic denture was applied and the woman obtained the proper use of her jaw.

This may help to answer some of the questions about using rib for transplantation, and also some of the problems of the growth of bone following transplantation.

Stephen S. Hudack (New York, N.Y.): The work of Dr. Kiehn and Dr. Glover represents, I believe, the work of martyrs. The patience and the fastidiousness necessary in some of this work is beyond my capacity, I am very frank to admit. I am really amazed to see the low incidence of infection that Dr. Kiehn and Dr. Glover report. At one time I contemplated trying to develop some tissue-soluble bone matrix substitute for this kind of work. Their results with grafting are so satisfactory that the idea of substitutes can now be disregarded.

Douglas Macomber (Denver, Colo.): It was my privilege, both overseas and in the zone of the interior to work with Dr. Kiehn on a great many of these cases, and I would merely reiterate our enthusiasm for iliac bone and using only the amount of cortex necessary to support the body of the graft. I question very much that a high per cent of

* Dr. Speed presented slides taken of this patient.

rib grafts would show the gratifying results we had with the iliac crest.

HARRY H. CAMPBELL (Toronto, Canada): Ladies and Gentlemen: I would like to add my thanks and compliment Dr. Kiehn and Dr. Glover on this very excellent presentation and the film they showed here last night.

In the Canadian Army during the war all cases of shell wound with bone loss of the mandible that we saw had bone grafts done soon after the wound was healed. The reason we did this was because our evacuation system was a little slower than yours, and we believed that the patients should have their bone loss replacement before being sent home. They were sent home with their fixation *in situ* wherever possible.

This, of course, meant that they were kept around from two and a half to three weeks after the soft tissue wound was healed, when we put the bone graft in, replaced the fixation and sent them back home when we could. If they had soft tissue defects, these were repaired and later on, the bone, too. We had results very comparable to Dr. Kiehn's, and I believe he saw some of our work when he was overseas. Antibiotic cover was used for from five to eight days following operation.

We believe very much as they do, that we should manage these cases in civilian practice with the same methods. I think this has been an excellent essay on the accepted surgical management of mandibular bone defects from any cause today.

I would like further to state that we have not found it necessary to ligate the external carotid artery in any of our resections of the mandible, but reserve this for major resections of the maxilla in case of tumor and so on. We have had no difficulty from hemorrhage in these cases.

CLIFFORD L. KIEHN (closing): I agree with Dr. Campbell that we have not had to tie off the external carotids in any of our cases even in total resection of the mandible. We believe that hemorrhage can be controlled very well without it.

Dr. Speed also mentioned the rib graft of the mandible without fixation. We also have been able to do that, particularly in the edentulous mouth in which fixation is very difficult to attain, with primary union of the grafts.

The subject of bone substitutes has been going on ever since Ollier first did a bone graft, and we still believe that these prosthetic appliances we are using are a temporary affair, so that the fragments can be held in normal position, allowing the patient to open his mouth and chew food fairly well until the tissues are healed adequately enough to receive the bone graft.

SIGNIFICANT ROENTGEN FINDINGS IN ROUTINE PRE-EMPLOYMENT EXAMINATION OF THE LUMBOSACRAL SPINE

A PRELIMINARY REPORT

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Salt Lake City, Utah

ONE of the newer innovations in the routine pre-employment physical examination of employees in industry is an x-ray examination of the lumbosacral spine. One June 1, 1948, this procedure was instituted by the Medical Department of a large industrial plant with which the authors are connected. Between that date and June 1, 1950, 3,000 lumbosacral spines of male applicants for work have been examined by this procedure. The age of these men has ranged from eighteen to sixty-five years. It has also been the policy at this plant since it was opened in December, 1943, to x-ray the chest of all would-be employees, exposing 4 by 10 inch stereoscopic films by means of a photoroentgen unit. The routine x-ray examination of the lumbosacral spine consisted in the exposing of 7 by 17 inch films in the anteroposterior and lateral projections, with the individual recumbent on the table and using a Potter-Bucky diaphragm. While an examination of this sort does not constitute a fully adequate roentgen examination of this portion of the spine, in that the latter should include not only anteroposterior and lateral films but oblique views as well, nevertheless this examination can be considered comparable in diagnostic value with the results obtained from a mass chest x-ray survey. With this thought in mind the authors believe that any pathologic condition or abnormalities revealed in a spine survey of this sort can be better demonstrated and evaluated by the making of additional films. This was done on several individuals examined in this series.

All of the films made in this survey have been interpreted by one of the authors of this paper (M. L. A.) and the findings have been carefully tabulated and analyzed. The present paper is a critical analysis of the pathologic conditions and anomalies encountered in these examinations. It will be noted in the tabulation of the results (Table 1) that the various conditions encountered are classified under five main groupings: (1) Degenerative processes, such as osteoarthritis and degeneration of the intervertebral disks; (2) post-traumatic lesions, comprising crush fractures of the vertebral bodies and fractured transverse processes; (3) congenital and developmental anomalies classified under the following headings: spina bifida occulta, sacralization of transverse processes, spondylolisthesis, ununited ring epiphysis, lumbarization of transverse processes and scoliosis; (4) postsurgical conditions consisting of spinal fusion procedures and laminectomy and (5) miscellaneous conditions, not all of which represent spinal disorders.

The condition encountered most frequently in this study was osteoarthritis of the lumbar spine; 408 cases (13.6 per cent) of this condition were tabulated. The high incidence of this condition can be explained by the fact that many of these individuals had been farmers, ranchers, miners and day laborers and in such occupations they had performed heavy manual work. The roentgen manifestation of this condition consisted of lipping and osteophyte formation of the bodies of the involved vertebrae, eburnation of the facets and in many cases actual bony bridging between the vertebral bodies. No attempt was made in interpreting these cases to differentiate between those representing a static osteoarthritis and the traumatic type of this disorder, since both of these types give largely the same roentgen manifestations. No cases were encountered in this study of rheumatoid spinal arthritis or Marie-Strumpell's disease.

Narrowing of the intervertebral space between two vertebral bodies is interpreted by

roentgenologists as indicative of degenerative changes in the intervertebral disk at this level of the spine; thirty-four cases (1.13 per cent) showed such narrowing of one or more intervertebral spaces. The practical importance of calling attention to this condition consists in the fact that such narrowing of an intervertebral space is usually regarded as indicative of a possible associated herniation of the intervertebral disk at this level of the spine. This possibility, of course, can be definitely proven or disproven only by means of myelographic studies. There were numerous cases of Schmorl's disease or Schmorl's nodules encountered in this study but these were not tabulated and hence are not included under the heading of degenerative changes of the intervertebral disk.

Wedging or narrowing of a vertebral body was interpreted as indicative of a healed crush fracture and was so tabulated. However, it is quite possible that some cases showing this finding may have been due to a previous healed Kummel's disease. There were seventy cases (2.33 per cent) which showed this finding and hence were interpreted as representing healed crush fractures. Many of these individuals also showed an associated traumatic osteoarthritis of the involved vertebra or vertebrae and adjacent vertebrae. The importance of having a permanent x-ray record of the spines of these men at the time of their initial employment cannot be overemphasised. There were also nineteen cases (.63 per cent) of old healed fractures of one or more transverse processes of the lumbar vertebrae. Some of these cases, however, showed non-union of the fragments.

In considering the congenital and developmental anomalies encountered in this study, it should be borne in mind that the lumbosacral region is the site of more anatomic variants and anomalies than any other portion of the bony skeleton.[1] In view of this fact no effort has been made in this study to tabulate all the normal bony variants and anomalies encountered. Hence this presentation does not concern itself with the commonly seen variants of the articular facets of the fifth lumbar vertebra, the presence of six lumbar vertebrae in place of the usual five and variations in the angle of stress between the fifth lumbar vertebra and the first segment of the sacrum. It is a moot question as to how great a role anomalies of the lumbosacral spine play in the causation of back symptoms. Bohart[3] states that developmental anomalies did not prove a source of symptoms in a large series of men he examined who were subjected frequently to severe trauma. On the other hand, Gillespie[5] in a series of 500 laminectomies found that 34.2 per cent of these patients had some sort of congenital spinal instability or anomaly. Also Meyerding and Pollack[6] state that congenital anomalies, such as spina bifida occulta and sacralization of the transverse processes, are a frequent source of lumbago. In any event we believe that the anomalies listed in this study are important not only as a causative factor in the production of symptoms but also, when revealed roentgenologically following injury, may be the basis for alleged disability and possible legal action.

TABLE 1
INCIDENCE OF PATHOLOGIC CONDITIONS AND ANOMALIES REVEALED IN PRE-EMPLOYMENT X-RAY EXAMINATION OF 3,000 LUMBOSACRAL SPINES

Condition	No. of Cases	Per cent
Degenerative Lesions		
Osteoarthritis	408	13.6
Degenerated intervertebral disk	34	1.13
Post-traumatic Lesions		
Crush fracture of body	70	2.33
Fractured transverse processes	19	.63
Congenital and Developmental Lesions		
Spina bifida occulta	177	5.9
Sacralization of transverse processes	151	5.03
Spondylolisthesis	89	2.96
Ununited ring epiphysis	42	1.4
Lumbarization of transverse processes	17	.56
Scoliosis	15	.5
Postsurgical Lesions		
Spinal fusion	6	.2
Laminectomy	2	.06
Miscellaneous Conditions not All of Which Represent Spinal Disorders		
Soft-tissue lesions, questionable lesions of spine, etc.	21	.7

The most commonly encountered anomaly was a spina bifida occulta or failure of fusion of the laminae of the involved vertebra. There were 177 cases (5.9 per cent) of this condition tabulated. There may be no symptoms from this anomaly, but some cases have been known to show progressive deformities of the lower limbs, instability of the lumbosacral region with low back pain and disturbance of micturition.[4] The great majority of these cases of spina bifida occulta involved the neural arches of the first segment of the sacrum and the fifth lumbar vertebra. No case of anterior spina bifida or congenital cleft of the vertebral body was observed in this series.

There were 151 cases (5.03 per cent) of sacralization of the transverse processes of the fifth lumbar vertebra. The importance of this condition lies in the fact that its existence very often causes back symptoms and may be regarded as one of the stigmata of a potentially weak or painful back.

The next most numerous anomaly was that of spondylolisthesis of which there were eighty-nine cases (2.96 per cent) tabulated. These cases presented varying degrees of this anomaly and in the majority the fifth lumbar vertebra was the site of involvement. In sixty-six of these cases it was possible to identify definitely an accompanying congenital break or spondylolysis in the neural arch of the involved vertebra. However, it is our belief that had oblique films been made on the individuals not showing a definitely proven break in the neural arch, such a condition would have been revealed. Bailey[2] made lateral radiographs of the lumbosacral spines of 2,080 draftees in order to determine the frequency of spondylolisthesis and its precursors. As a result of this study he was able to demonstrate a spondylolysis or interarticular isthmus hiatus in the neural arch of practically all of his cases of spondylolisthesis. In this study no tabulation was made of spondylolysis unless there was an actual accompanying spondylolisthesis.

There were forty-two cases (1.4 per cent) of ununited ring epiphysis of the lumbar vertebrae. This condition most commonly occurs in the lumbar spine. Chronic arthritis sometimes occurs in the false metaphyseal joints of this condition and may cause symptoms of pain. This condition also has some medicolegal importance, as one of the authors has given expert testimony in court in two instances in which it was alleged that this anomaly represented a chip fracture of a vertebral body.

There were seventeen cases (.56 per cent) encountered of so-called lumbarization of the lateral masses of the first segment of the sacrum. This condition has the same clinical significance as sacralization of the transverse processes of the fifth lumbar vertebra and in many cases it is difficult to differentiate the two conditions.

Finally, among the developmental anomalies tabulated were fifteen cases (.5 per cent) of scoliosis. Most of these were judged to be developmental in nature, although it is quite likely that some of them may have represented the aftermath of poliomyelitis. However, one of them was due to a hemivertebra of the fifth lumbar vertebra.

The postsurgical conditions encountered in this series consisted in six cases (.2 per cent) of spinal fusion and two cases (.06 per cent) of laminectomy. Without a knowledge of preceding clinical history of these men and judging from the roentgen appearances entirely, it was concluded that these procedures had been done either because of preceding crush fracture or herniated intervertebral disk.

A total of twenty-one individuals presented miscellaneous disorders, some of which were not related to the spine and hence are not represented in our figures of total morbidity. Two of these individuals showed a generalized vertical striation of all of the bodies of the lumbar vertebrae, the exact significance of which was uncertain. The striation seen in these cases somewhat resembles the striation seen in cases of osteoitis deformans or Paget's disease. One of these men had other films made of his skull and long bones which showed no roentgen evidence of Paget's disease.

From a medical standpoint this study is of interest and value in that few other comparable large x-ray studies have been made of the lumbosacral spine of supposedly normal individuals. Consequently the pathologic conditions revealed and the abnormalities encountered should constitute a fairly accurate estimate of the incidence of these conditions in the adult male working population of the country. We believe that a pre-employment x-ray examination of the lumbosacral spine is a very worth while procedure that can be adopted with profit by all large industrial plants and particularly those whose workers engage in strenuous occupations. We are also of the opinion that this

procedure, as performed in this instance, is merely a rough screening survey so far as demonstrating actual pathologic conditions of the spine. Hence the accuracy of these examinations and the better demonstration of disorders revealed would be obtained by the exposing of not only films in the anteroposterior and lateral projections but also by using oblique and other special views. This, of course, would greatly increase the cost of such a study and would impose a far greater load of work upon the technicians doing the examinations.

Besides the scientific medical data revealed by this study the latter has several practical advantages from an industrial standpoint. These may be briefly enumerated as follows: (1) The examination constitutes a permanent record of the condition of an employee's spine at the time of his initial employment and hence should be of great usefulness in evaluation of subsequent injuries and morbid conditions involving this portion of the bony skeleton during the term of the individual's employment. (2) It should enable the Medical Department of the company to recommend for non-employment those men whose back conditions presented a medicolegal hazard. (3) It also should enable the Medical Department of the company to see that men with potentially weak backs are assigned to jobs compatible with the ability of the individual's spine to withstand the wear and tear of heavy and strenuous manual work. (4) The examination should also be of great assistance in the fair and just adjudication of medicolegal problems arising during the periods of the individual's employment.

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DISCUSSION

Martin C. Lindem (Salt Lake City, Utah): In discussing Dr. Allen's paper, I would like to say that the prime objective in undertaking this project is to disclose the pathologic conditions which might later allegedly become disabling, principally because of occupational stresses, namely, those minor or major degrees of trauma that are borne in industry; and, less important, to prove, if possible, whether there is ground for that assessment of responsibility placed upon a single x-ray finding made by the orthopedists and industrial rating boards when they evaluate residual disabilities in injured backs.

The subjects examined were an admixture of local people and migratory workers from all parts of the country seeking industrial employment, and represent a cross section of supposedly healthy workers of this country. With very few exceptions, the pre-employment history and physical examination did not reveal either subjective or objective evidence of disability in the lower back.

We have noted a marked decrease in verified prolonged disabling traumatic lower back conditions, usually called traumatic lumbago and back strain, as well as subjective backaches, since we have been able to confront the patient with conditions existing at the time of his employment. Our findings have to some extent exerted a salutary effect upon the doctor who believes that all anatomic-pathologic conditions found by x-ray must have a counterpart in the realm of the pain sense of the patient, even though the objective evidence to the contrary is present. We are disinclined to believe that an employee will malign about his back unless he finds a subjective coefficient in his doctor.

Likewise, industrial boards, which adjudicate claims for compensable disability in the back, may observe the large percentage of backs with x-ray-demonstrable abnormalities who masquerade as normal, and they may find that x-ray abnormality *per se* is not the cause of the disability but that the traumatic state is a superimposed and curable condition, such as it would be if the x-ray findings disclosed normal anatomy of the spine.

Orthopedic surgeons (I beg your pardon for putting a torch to them) may well ponder the large number of x-ray disclosures of narrowed intervertebral spaces, spondylolisthesis of major grade, articulated transverse masses of lumbar and sacral vertebrae, all symptomless in this study and getting along well without disc excision, fusion or arthrodeses.

One word could be said with regard to the cost of adding x-ray studies to the above indicated type of physical examination. In a survey of the larger groups, the medical department will have the equip-

ment and skilled technicians to prosecute the technical and material expense; then the interpretation is done *en masse* by roentgenologic medical specialists. It is to be cautiously remarked that for smaller industrial concerns, the radiologic fraternity, if I may use the term, should combine to arrange for this work at equitable cost per individual.

I will mention that the industrial concerns were put to very nominal cost for matériel and professional work to carry on this study, but the illuminative information far transcends the cost evaluation.

EDGAR L. GILCREEST (San Francisco, Calif.): This paper interested me very much, particularly the magnitude of these investigations consisting of 2,500 patients being x-rayed. A study like this is very valuable when one analyzes it. I would like to ask Dr. Allen how many of the patients whose backs were x-rayed and found abnormal were denied work.

Probably they can be rejected here in Utah but not in California. For example, in San Francisco the employer sends down to the hiring hall and he is sent some men whom he has to take for better or for worse. I know of one man who fell dead while lifting a regular load with his co-worker, work he had been doing for twenty years. There was no accident. The autopsy revealed that he had a subtotal occlusion of the coronaries. He had ceased work for six months before because of his heart and went back against the advice of his doctor. He died of natural causes. Nevertheless, the employer had to pay the complete death penalty because the man died while working.

There is no condition that causes so many lost days in the United States as backache. The question comes up in these cases as to whether the employer should pay for aggravation when a man is employed with osteoarthritis. The employer is stuck if there is a history of the worker not losing days of work. If he lifts something and slips, the employer is held for an aggravation of a pre-existing disease. It is a very delicate question that is put on the shoulders of the doctor. He must evaluate the condition and be perfectly fair and square to both employee and employer as to how much of the backache is due to the supposed or alleged injury.

I think often doctors are very unfair to the injured man, and I think many times, of course, they go overboard to the other side. Therefore, I think a paper like this should make us think how to evaluate these cases and render decisions based upon many factors of pathology and also the man's integrity. I had one patient who had an old compression fracture of the upper lumbar vertebra and he never realized he had had a fracture years before.

M. LOWRY ALLEN (closing): In answer to Dr. Gilcreest's question about disinclination to turn some of these men down for employment, I think that has been the policy of the chief surgeon. Of course, the roentgenologist merely reads the films and tells what the films show, and it is up to the chief surgeon of the company and his staff to decline for employment certain of these individuals. But I think no man with a crush fracture or no man with spondylolisthesis has been employed. I think some of the other men have been employed with the reservation that they be assigned to some light work.

This problem has been rendered somewhat easier in this case, or in the case of this industrial plant, because of the fact that it has been a new industry here in the state and consequently they could be a little "choosey" in selecting their employees. If it had been an old established industry where this thing had been innovated, I think we would probably have got into the same troubles as Dr. Gilcreest speaks of, namely, that the unions would have compelled the company to hire these individuals, regardless of the state of their backs.

PRINCIPLES OF MANAGEMENT OF OPEN WOUNDS OF THE HAND*

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THERE are two basic concepts of present day wound care. The first concept is that the healing process of tissues is a natural phenomenon which can be favored by placing and maintaining the tissues in a suitable environment, keeping them nourished and at rest. The second concept, based on extensive clinical observation and controlled bacteriologic studies, is that wound infection is due almost always to bacteria introduced into the wound after and not at the time of injury and favored by the presence of culture media upon which bacteria may feed.

Premised upon these concepts the care of all open wounds is based upon a few simple principles which have been established and proved largely by intelligent clinical observation and by logical deduction from observed facts.

There are two great temptations which the surgeon must resist in his care of the open wound: the temptation to apply a "healing balsam" and to leave the wound open so that it can "drain." All that the injured tissues require is to be replaced in their original anatomic relationships after the débris of trauma has been cleared away, and then to be left alone to deal as they see fit with the job of repair. Materials for this repair in the shape of proper foods and vitamins and some assistance in the form of antibiotics to stave off bacterial invaders will be helpful; but beyond this the surgeon's task, after adequate initial operation, is minimal. When healing is delayed or disturbed it will usually be found that the error is either in not clearing out the débris or in adding to it; there will be foreign material and dead tissue, either the result of the original wound or the result of surgical trauma.

Obviously the problem is not as simple as all that but the basic philosophy, I believe, is sound. The advent of antibiotics and of more logical resuscitative and replacement therapy have made possible surgical feats not accomplished before. But success of the actual surgical procedures depends upon observance of the same general basic principles.

In the case of open injuries of the hand the principles of care may be divided into two groups: (1) those having to do with care of open wounds in general and (2) those having to do specifically with wounds of the hand from the standpoint of functional and technical considerations peculiar to the hand.

The general principles of wound care were slowly established after Friederick's notable experiments, clearly demonstrated after the first world war, forgotten and then re-enunciated by Koch, Reid and others in this country and by Boehler in Vienna. But their voices were overpowered with our advent into World War II by Trueta's teaching and by the Siren of local sulfonilamide. The principles were then "rediscovered" during the African campaign and finally accepted as basic for wound care during the subsequent phases of the war.

Immediate and continuous protection of the open wound from secondary bacterial contaminants starts at first-aid with the application of a voluminous sterile compression dressing. During all subsequent phases of care for as long as the wound remains open every precaution is taken to prevent secondary contamination from the environs. All examinations and dressings are done with surgeon and assistant masked and with forceps' technic.

Promptness in rendering care, both initial first-aid and primary definitive care, is of great importance. The longer the delay between injury and first-aid and between first-aid and primary surgery, the less are the chances of restoring the tissues to their normal relationships and the longer will be the period of healing and functional return. Most wounds are relatively clean when incurred; if promptly covered, sec-

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ondary contaminants may be kept from them until primary definitive care is given. The longer the delay in these steps, however, the greater are the possibilities of contamination and of proliferation of contaminants in unexcised débris and detritus, and the spread of invasive contaminants into healthy tissues. The primary care of open wounds is an emergency which should be delayed only long enough to permit proper examination of the patient and the wound and for preparation for operation. The patient cannot be sent to the ward until morning or until the afternoon after completion of the morning's scheduled procedures. Progressive edema and hemorrhage may render operation difficult, infection certain and some types of repair impossible.

Preparation of the wound for operation consists in *careful cleansing* of the skin about the wound and then of the wound itself with soap and water and liberal irrigation with saline solution, all under the strict asepsis of operating room technic. Occasionally a solvent is valuable for removing grease and other water insoluble substances. This is a cleansing not a sterilizing procedure.

Excision of devitalized tissue is a procedure which calls for good judgment and the greatest care. Starting with skin excision, the surgeon proceeds methodically through the wound removing all tissue so severely damaged that necrosis seems inevitable. It is here that knowledge of the nature of the injury is of value. Severe crushing wounds lead to more serious damage than mild crushing or tearing; tearing injuries are more severe than lacerations and lacerations more severe than sharply incised wounds. It is sometimes difficult to determine whether or not tissue is sufficiently damaged to succumb. If we know that the injured area has been crushed by a heavy weight, we can be pretty sure it will be non-viable. I cannot ascribe to the opinion occasionally expressed that non-viable skin flaps be deliberately sutured back into position for a few days to serve as temporary cover of a raw surface. We have seen serious trouble, deep infection and extensive fibrosis from just this practice. Although adequate excision will often pose difficult problems of closure, these should not be the determining factor. On the other hand, the surgeon must not excise viable tissue simply to make subsequent care and closure easier.

Adequate bemostasis is necessary to insure satisfactory healing. Vessels are ligated as they are encountered during operation and the wound is not closed until all bleeding is under control. A firm resilient pressure dressing applied after closure will help control oozing from tiny vessels but cannot be relied upon to stop real bleeders.

Anatomic restoration of the tissues consists in deep repair and primary closure unless contraindications obtain.

Deep repair will depend upon a number of factors: certain tissues, e.g., joint capsules and fractures, are always repaired or reduced, nerves are usually repaired, while the feasibility of tendon repair will depend upon the degree of contamination and the possibility of securing adequate exposure without disseminating virulent organisms. The surgeon should replace the tissues as nearly as possible into their original relations to each other. Where actual loss prevents such restoration, other solutions must be sought.

Closure of the wound is of the greatest importance in securing healing and may be accomplished in all but a few injuries. Closure is often the most difficult part of the operation. If the skin excision has not been too great, the edges may be brought together by suture, hence the surgeon's care not to excise viable skin. Often very irregular tags may be dovetailed into each other to secure quite acceptable closure. If because of tissue loss (traumatic amputation, etc.) there seems to be an excess of skin, it should be saved until the end of the operation and utilized or discarded as conditions indicate.

If closure cannot be accomplished by suture, it will usually be possible by split skin grafts occasionally associated with rotation flaps in cases in which bone, joint and tendon are exposed. In this latter instance it may be necessary to resort to pedicled flaps in case rotation flaps cannot be maneuvered into position.

In a very few instances the surgeon may be justified in leaving the wound open for secondary closure later. Indications for this procedure are rare in civilian surgery since patients are usually seen sufficiently early to permit closure. Obviously the wound seen late with frank fulminant spreading infection cannot be closed. In some cases seen late and with a history of a good deal of tampering in which excessive secondary contamination has undoubtedly occurred, the surgeon may elect to cleanse and

excise and to omit primary closure in favor of delayed closure on the fifth to seventh day.

The application of a *compression dressing* accomplishes several ends: It obliterates dead space and helps to put the tissues back into normal pressure relationships. By obliterating dead spaces and compressing capillaries, the dressing discourages postoperative oozing and the formation of hematomas. The surgeon must not, however, depend upon this for hemostasis; ligation of vessels must be carried out conscientiously during operation. The pressure tends to discourage edema, a most troublesome complication, especially in the hand. Lastly, the pressure assists in the immobilization of the part.

Rest for the injured part is secured by use of a splint or plaster cast. The position in which the part is put at rest is of some importance. Ordinarily, with extremity wounds the part is splinted in the position of optimum function. However, situations may arise in which, because of fracture, tendon and nerve repair, or dislocations, the position chosen must be one suitable for the special condition.

Elevation favors venous drainage and discourages edema and thrombosis. The part should be above heart level. Excessive elevation has never seemed necessary to me.

Just where the antibiotics fit into the picture I do not think has been adequately crystallized. Their almost universal usage and their well nigh harmlessness make scientific case study difficult. We can observe the effects upon acute spreading infection and can compare the course of these processes today with calamitous experiences in the pre-antibiotie days. But experiences with the treatment of open injuries is something quite different. The treatment afforded the open wound today and the general level of wound care fifteen years ago are quite different. The general principles of wound care as outlined above, when carefully followed, without the use of antibiotics, resulted in almost as high a percentage of good results as one sees in good wound care today. General experience and the carefully controlled observations of Meleney have borne this out. The antibiotics help to prevent the spread of infection from a wound but they do not compensate for neglect of cleansing, excision and rest. It is possible that the antibiotics and chemotherapeutic drugs have extended the safe period for wound excision by several hours, but no exact clinical studies substantiate this. They will not sterilize a wound or rid it of necrotic tissue. Better and earlier care of open wounds has undoubtedly been of greater significance than the antibiotics.

When we deal with open wounds of the *hand in particular*, the general principles of care are the same. There are, however, certain specific considerations dealing with the technic of operation and the functional restoration of the hand.

It has been aptly stated that disregard of good technic in the care of wounds of the hand is followed by more serious consequences than similar disregard elsewhere. I do not care to belabor that point especially. Disaster may follow in the wake of careless surgery anywhere, but in the hand even minimal disturbances may be followed by very great functional loss. To secure satisfactory results in surgery of the hand requires strict adherence to recognized principles.

Anesthesia for any but minor injuries should be a general anesthetic. Local infiltration is difficult for any but minor injuries and must often be augmented by a general anesthetic. The blood pressure cuff becomes quite painful and local anesthesia does not control this distress. Then, too, the frequent need for enlarging incisions in which nerve and tendon repair is needed, the need for removal of skin grafts and the manipulations often required when fractures are present militate against local anesthesia. We have had little experience with plexus block anesthesia which has not gained the great favor in this country that it enjoys abroad.

A bloodless field secured by means of a blood-pressure cuff is almost a "must" in hand surgery, especially for identification of divided nerves and tendons. The cuff is put up to 280 mm. Hg after a few moments of elevation of the arm. It is held there until the initial cleansing and excision are accomplished and the extent of repair determined upon. Then the cuff is released and after a few moments of pressure with a moist laparotomy pad the bleeding vessels are ligated and the cuff again inflated where it remains until the final compression dressing is applied.

During the period when the cuff is released the surgeon may secure some useful information by watching the rate of return of blood into questionable areas of skin. In an occasional case with very severe crushing of the tissues we

have refrained from using the cuff since we have not wished to add an hour or so of anoxia to already badly damaged tissues. In these cases extensive deep repair and exploration for nerve and tendon stumps do not come into consideration.

Saving all possible skin tags is as important here as in facial wounds. Irregular viable tags may often be fitted together to form a quite serviceable surface. When fingers are sacrificed, it is often possible to save much of their skin and use it for covering raw surfaces in the palm or on the dorsum. Rotation flaps should be used when possible to cover surfaces requiring full thickness skin. No other skin will quite replace hand skin.

Enlarging incisions on the hand for exposure of nerves and tendons must be made to follow physiologic lines. Especially vicious are midline incisions so often seen crossing an originally oblique or transverse wound. These must be unconditionally condemned as one of the most serious complicating factors in secondary repair. Transverse wounds may be enlarged by prolonging either end to the side of forearm or digit and then continuing in a longitudinal direction proximally or distally along the side. *Avoid* the midline and *follow the folds* should be the rule.

Save all possible finger length. In traumatic amputations, even when fingers have been extensively denuded, skin covering should be provided rather than resorting to higher amputation to secure closure. Split grafts, rotation flaps or pedicled flaps are all at the disposal of the surgeon and he should be prepared to apply any or all of these measures to secure coverage of a denuded finger.

Repair of divided tendons should be undertaken primarily if conditions are suitable. The secondary repair, however, offers a good prognosis and the surgeon should not hesitate to omit primary repair if, for any reason, primary suture seems contraindicated. If reaction develops after primary suture, the later operation is extremely difficult and the prognosis is poor. For primary repair to be successful the wound must be seen early, within four hours and preferably under two hours. The wound must be reasonably clean when first seen, i.e., it should have been covered at once as first-aid and not tampered with afterward. It is seldom wise to attempt tendon repair if previous attempts have been made elsewhere. There is no universal agreement on the course to pursue in repair of flexor tendons when divided in the fingers. While it is a generally accepted principle that only the profundus should be repaired, a great many surgeons believe that primary repair is seldom justified and recommend secondary repair usually by tendon graft in all such cases. My personal practice is to perform a primary repair of the profundus tendon only in the favorable case. A further prerequisite for primary tendon repair is the ability of the surgeon to do this type of surgery and the proper facilities for carrying it out.

Divided nerves should be approximated in any wound except, of course, those with already established infection. It is not necessary to dwell upon the technic of nerve suture. The surgeon should be cognizant of the great frequency of nerve division in injuries of the hand and should be able to distinguish nerve from tendon. The digital nerves must be repaired in the same fashion as the large nerve trunks. There has been a great deal of controversy lately over the advisability of leaving nerve repair for secondary operations. My personal opinion favors primary suture in all cases in which technical facilities are available. We have never found it necessary to resuture a nerve which we have sutured primarily in a wound which subsequently healed by primary intention.

The hand should be *immobilized* in the position of function in most instances of acute open injury. This position is well known but we still see hands immobilized flat with fingers together and the thumb at the side of the hand. The indications for splinting of the hand in any other position than that of function are relatively few. Following nerve and tendon repair the wrist and fingers should be placed in a position to relax the repaired structures. This will require flexion position following flexor tendon and median and ulnar nerve repair, and extension of wrist and fingers following extensor tendon repair. For almost every other type of injury, including open fractures, the position of function is the optimum in which the hand should be splinted.

Certain *functional considerations* are of importance in the repair of open wounds of the hand. There are three main basic functions of the hand: sensory perception, grasping and pinching. Sensation depends upon intact nerves and obviously these nerves must be intact to the finger tips where the most discriminating of

sensation is required. The finger tips are sensory end organs, hence the need for repairing even distal portions of the digital nerves. From the motor standpoint nerve repair is likewise of great importance and the surgeon must not forget that although the forearm musculature and the long tendons passing into the hand receive their innervation in the forearm, the intrinsic muscles are innervated by branches of the median and ulnar nerves after they reach the hand and these small motor rami must be sutured if they have been divided.

Both grasping and pinching action of the hand depend upon the ability to oppose fingers and thumb. Without this no pinching action is possible and grasping is very much reduced, hence the requirement that the web space between thumb and palm be kept open and the thumb rotated and also that all possible length to the thumb be preserved. In this connection, however, it must be remembered that the absence of the thumb does not completely cripple a hand and is not in itself an indication for plastic restoration of the digit. The hand can grasp and can perform many actions in the absence of the thumb and replacement should not be undertaken until the patient has made a fair trial of use without it.

Grasping, especially strength in grasping, is dependent upon not only an opposable thumb but also upon breadth of the palm. This consideration makes one hesitate to amputate the index or little finger through the metacarpal in a patient who must use the hand for labor. The second and fifth metacarpals add about 25 per cent each to the width of the palm and increase the area of contact by that much. Functioning bases of the corresponding proximal phalanges likewise add to breadth of grasp and should be preserved. Hence it is my belief that although oblique amputation through the index or fifth finger metacarpal yields a very fine cosmetic appearance to the hand, the procedure should be reserved for individuals in whom appearance is more important than grasping. It is probably not an operation for the laboring man.

The pincer action of the hand, dependent on opposable thumb to index and middle fingers, may be preserved with even a minimum of joint action provided the fingers are moderately flexed and the thumb rotated. In the acute injury the surgeon should preserve length of digit and should so splint the hand that even with a minimum of action a pincer effect can be retained.

SUMMARY

The principles of care of open wounds have developed from an appreciation of the factors dealing with wound healing and from a knowledge of the source of wound contaminants. The introduction of chemotherapeutic drugs and of the antibiotics have not altered the principles of wound care.

These general principles of care are: (1) Immediate and continuous protection from contaminants; (2) primary surgical care at the earliest moment; (3) mechanical cleansing of the wound; (4) surgical excision of devitalized tissue; (5) careful hemostasis; (6) anatomic restoration of the tissues; (7) closure of the wound; (8) compression dressing; (9) putting the part at rest and (10) elevation.

Specific principles, in addition to the above, apply to the hand because of technical and functional considerations. These are: (1) General anesthesia for all but the simplest procedures; (2) bloodless field secured by blood-pressure apparatus; (3) save all viable skin tags; (4) save all possible finger length; (5) tendon repair only in suitable wounds; (6) nerve repair in all wounds; (7) splint the hand in position of function except following nerve and tendon repair and (8) functionally, the hand is a grasping, pinching, sensory end organ.

PRIMARY TENORRHAPHY AND NEURORRHAPHY OF THE HAND AND FOREARM*

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THE seriousness of injuries to tendons and nerves of the forearm and hand has been stressed frequently by Koch and Mason[1,2] Bunnell,[3] Spurling,[4] Pollock and Davis,[5] Haymaker and Woodhall[6] and others.[7–13] In spite of the added experience gained from the management of many such injuries sustained in two world wars, the problem of tenorrhaphy and neurorrhaphy remains a challenge for the surgeon to diagnose correctly, repair surgically and direct physical therapy properly to obtain uniformly good results.

In World War II thousands of soldiers received serious wounds of their upper extremities, many of which dealt specifically with the problem of repair of nerves and tendons. The Surgeon's General Staff has been complimented on the success of the management of these injuries. In World War II (in contrast to World War I) the basic surgical principles were to protect life by control of infection and to limit definitive therapy to special surgical centers remote from the battle zones. From these experiences in World War II excellent observations have been reported regarding tenorrhaphy and neurorrhaphy. In civilian traumatology the same surgical principles do not apply since most, if not all, of the factors connected with the injuries in these two groups of cases are different. For purposes of clarity the discussion will be limited to each general problem.

PRIMARY TENORRHAPHY

Tenorrhaphy, either primary or secondary, must not be considered a minor surgical operation. In such a procedure the technical steps are difficult and, although life may not be endangered, the function of a vital part of the body may remain at stake. I was impressed some years ago, while conversing with an older, nationally known surgeon, when he uttered these words, "I know many surgeons in this city to whom I wound entrust removal of my appendix, but I do not know one capable of suturing my severed tendon."

Among the first and most important considerations of primary tenorrhaphy are the indications and contraindications.

Indications. The indications for primary tenorrhaphy in the hand and forearm are as follows: (1) In simple, clean, freshly incised wounds the *duration* of which has been *less* than *six* hours; (2) in comparable wounds involving severance of any of the extensor tendons, either single or multiple; (3) in comparable wounds involving the flexor tendons in the distal forearm, at the level of the volar annular ligament and/or distal to the annular ligament but proximal to the tendon sheath; (4) in comparable wounds involving the flexor tendons within the flexor tendon sheath, provided the distal and proximal ends of the flexor digitorum sublimus tendon are resected to provide adequate gliding space for the profundus tendon. Occasionally, the proximal end of the sublimus tendon is sutured to the distal end of the profundus, which requires resection of the insertion of the sublimus tendon; (5) in comparable wounds under the stated conditions but in which there is associated nerve injury and/or compound fracture of bone without disruption or displacement of bone continuity; (6) after the proper conversion of a contaminated wound into a clean wound by good surgical methods. This principle has been broadened by the use of antibiotics and chemotherapeutic agents. Control of infection from staphlococcus, streptococcus and gram-negative organisms has made primary tenorrhaphy far safer than ever before.

Contraindications. Contraindications for primary tenorrhaphy in the forearm and hand are as follows: (1) When there are other associated injuries of a serious variety in a patient, such as cerebral, thoracic and/or abdominal

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trauma, obviously more important to life than the injured extremity; (2) when the *wound* of violence, regardless of simplicity, *has not* received *definitive treatment* within six hours after injury. If one attempts primary repair under adverse conditions, infection almost certainly will occur and a poor functional result will follow. Under these circumstances we advocate proper surgical cleansing of the wound and simple closure of the skin. Chemotherapeutic drugs should be administered to these patients. Within a short period of time (two to four weeks) secondary tenorrhaphy (with or without tendon graft) can safely be done. (3) When patients are semiconscious due to head injury or alcohol, primary tenorrhaphy is contraindicated. Such patients should not be given any general anesthetic agent; they are too uncooperative for regional novacain block and their general behavior precludes proper surgery; (4) when tendons are interrupted by severe crushing or mangling types of violence causing destruction and avulsion of skin and subcutaneous tissues of the forearm and hand. Under these circumstances good surgical judgment is of paramount importance. To salvage all living tissue, excise all devitalized tissue, convert a contaminated wound into a clean wound, to close all surface defects and obtain primary healing are the accomplishments to be sought. Secondary tenorrhaphy can be planned as an elective procedure after a more accurate evaluation of the situation has been made. (5) When wounds of violence of the flexor tendons in the digits are extremely serious, having torn the flexor tendon sheath, severed a joint capsule and disrupted continuity of the phalangeal bone, primary tenorrhaphy should not be the procedure of choice. These circumstances require proper care for soft tissue healing. Secondary tenorrhaphy, usually with tendon graft, is preferable.

Comment. In our opinion primary tenorrhaphy should be instituted as definitive treatment under the conditions indicated. For the most part we have obtained satisfactory results from primary repair under these conditions for all tendons except the severed flexor group located within the tendon sheath and specifically within the digit. Colleagues have referred to this area as "no man's land." Perhaps a better terminology would be "some man's land." In a recent report we[14] summarized the results of primary tenorrhaphy of flexor tendons in the hand. (Table 1.)

TABLE 1
PRIMARY TENORRHAPHY OF THE FLEXOR TENDONS IN THE HAND—ANALYSIS OF RESULTS IN SIXTY-FIVE CASES AT FOLLOW-UP EXAMINATION

Location	No. of Cases	Results			
		Satisfactory		Unsatisfactory	
		No. of Cases	Per cent	No. of Cases	Per cent
Thumb	9	8	88	1	11
Finger	32	20	62	12	37
Palm	24	20	83	4	16
Total	65	48	74	17	26

PRIMARY NEURORRHAPHY

A great volume of surgical literature has been written regarding the management of injuries to the numerous peripheral nerves of the body. To review this subject would add nothing but confusion to issues currently debatable. Spurling and Woodhall[15] have recently discussed the experiences of peripheral nerve injuries in World War II based upon observations made through the Army Peripheral Nerve Registry. Although in this conflict there were 20,000 or more peripheral nerve casualties treated by many neurosurgeons, all of the patients have not yet been reviewed by the registry and only now has sufficient time elapsed to evaluate the final functional results. The same observers agree that the majority of nerves, if not all, were damaged as a result of high velocity bullets and shrapnel. Most of us would agree that war injuries have no counterpart in civilian practice. To reason by inference that the correct method of management of peripheral nerve injury in civilian practice is the same as for war injuries may be misleading. This is certainly true for many soft tissue wounds, for gun shot wounds of the abdomen and for many other wounds which, in the individual civilian patient, can be corrected satisfactorily by primary definitive surgery, whereas under war time conditions circumstances would prohibit such procedures on hundreds of wounded soldiers.

Spurling and Woodhall offer clinical and neuropathologic data to substantiate their belief that high velocity bullet injuries are best managed by "early nerve surgery" and, by their own definition, on a time basis within three to six weeks after injury. In civilian practice the great majority of divided nerves in the hand and forearm are the result of simple, cleanly incised, deep wounds, or sharp penetrating wounds from knives, glass and metal, frequently associated with severed tendons and less frequently with compound fracture of bone. These are the patients in whom the question of primary neurorrhaphy arises.

Indications. In our own clinic the indications for primary neurorrhaphy are as follows: (1) In simple, clean, freshly incised wounds the duration of which has been less than six hours; the surgical technic we advocate is based upon the general principles of wound management discussed by Stevenson and Reid[16] and Reid and Carter.[17] Anatomic dissection is required and all structures are identified before reconstruction is begun. In such wounds division of the nerve trunks is usually by simple section. By the use of a pneumatic blood pressure cuff applied around the arm as a tourniquet the field may be kept free of blood and the severed ends of the nerves can be found easily. When tendons are damaged in association with nerve injury, this technic prevents suturing nerves to tendons, a pitfall in surgery which needs no further comment. Infection should not occur with proper surgical care in conjunction with the administration of antibiotics and chemotherapeutic agents. Since this statement is true, primary neurorrhaphy affords immediate continuity of the damaged nerve, early regeneration of the axones has been made possible and a period of delay and observation has been obviated. (2) In penetrating puncture wounds the duration of which has been less than six hours and in which a positive diagnosis of peripheral nerve damage has been made; in such an injury not infrequently only a nerve is severed. These patients are usually first seen within thirty minutes to three hours following the injury. Good surgical care embodies the principles of correct diagnosis of nerve damage, early definitive treatment by adequate exploration of the wound and primary neurorrhaphy. (3) In comparable wounds with both tendons and nerves damaged although the latter may be much less important than the former. For example, if four or more flexor tendons in the hand are severed distal to the volar annular ligament, in association with damage to a branch of either the median or the ulnar nerve, primary tenorrhaphy most certainly is indicated. To repair the tendon injury and disregard nerve injury is an unexplainable attitude in reconstructive surgery. One may question whether surgery has become so specialized that each anatomic part warrants a *certified* mechanic. I am convinced that the surgeon's attitude toward the task at hand plus his technical ability are as important factors in neurorrhaphy as the factors of time, method and suture material used. (4) In comparable wounds associated with compound fracture of bone which is not grossly deranged and which will not require manipulation and traction after closure of the wound. In these patients the surgeon can decide by roentgenograms before operation whether the compound fracture or the nerve injury looms as the major problem. When the compounded fragments of a phalanx, metacarpal or carpal bone are in good position and require no special means of reduction or fixation except adequate splinting of the entire hand, primary neurorrhaphy is indicated.

Contraindications. There are some contraindications to primary neurorrhaphy and they are as follows: (1) Comparable to primary tenorrhaphy, primary neurorrhaphy should not be attempted in clean, freshly incised wounds, the duration of which has been more than six hours, before definitive treatment has been instituted. The same principles apply in that the laceration should be cleansed, devitalized tissue and foreign material removed and the skin approximated by sutures. In the immediate postaccident period (within two to four weeks) after adequate chemotherapy delayed neurorrhaphy should be done. (2) In associated serious injuries to the head, thorax or abdomen there is no question of propriety of the procedure. Peripheral nerve injury is a secondary issue and primary neurorrhaphy should not be contemplated. (3) Primary neurorrhaphy is contraindicated if the procedure in any way would imperil life. Severe peripheral circulatory collapse due to blood loss, cerebral contusion or concussion and extreme inebriation are only a few of the predominant precarious conditions. (4) Primary neurorrhaphy is contraindicated in the severe crushing or mangling types of violence to the hand and forearm. Gunshot wounds, high velocity bullet wounds and shrap-

nel injuries would fall into this category. Moreover, in such wounds the nerves are extensively damaged in continuity, or segments of them are torn away. In either instance the widespread loss of tissue immediately calls for the surgical principles of saving life, salvaging all viable tissue in the extremity, preventing infection, closing open wounds and, finally, a delayed reconstructive period in which single or stage operations will give the maximum degree of functional return. Such injuries may require either neurolysis or nerve graft to accomplish secondary neurorrhaphy.

Comment. The surgical technic of neurorrhaphy does not come within the scope of this discussion. At present and as a result of the experiences in World War II with peripheral nerve injuries, the debatable issue in civilian practice is primary neurorrhaphy (nerve suture within six hours) or early nerve surgery (nerve suture within three to six weeks). From our own experiences at the Cincinnati General Hospital we are convinced of the rationale of primary neurorrhaphy when it is not contraindicated.

SUMMARY

In civilian practice the majority of divided tendons and nerves in the hand and forearm are the result of simple, cleanly incised, deep wounds, or sharp penetrating wounds from knives, glass and metal. We believe that these wounds are decidedly different from those wounds produced by high velocity bullets or shrapnel. Specific indications and contraindications for primary tenorrhaphy and primary neurorrhaphy have been stressed. By following the outlined surgical principles we have obtained satisfactory results.

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DELAYED TENDON REPAIRS*

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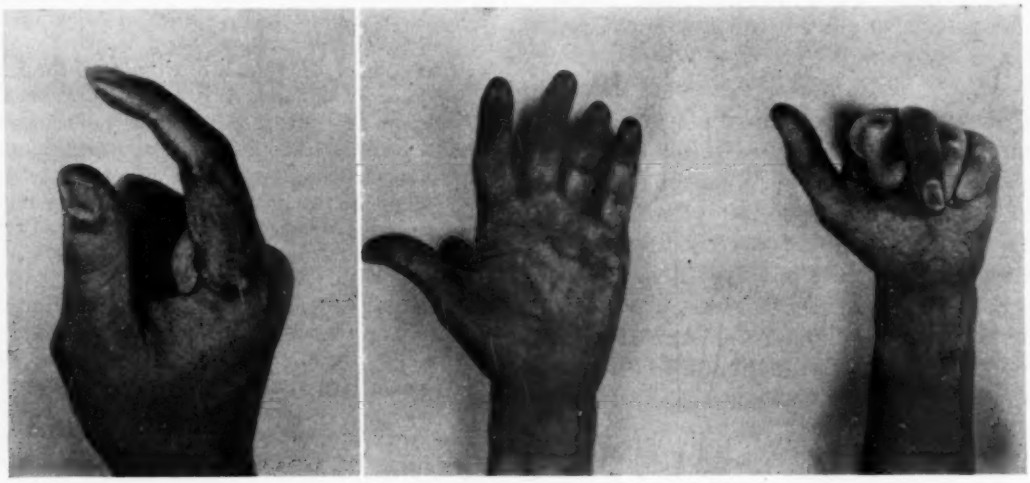
IN considering delayed tendon repairs one is dealing with a two-edged sword. In many incidents tendon repair should be delayed but the surgeon is so intrigued at the presence of the tendon ends in the vicinity of the wound that he will attempt to suture them immediately. On the other hand, tendon repairs frequently are delayed purely by accident as an inadequate diagnosis has been made. As a rule, repairs in the so-called "no man's land," so ably fenced off by Dr. Bunnell, should be secondary and accomplished by grafting. Unfortunately, this gospel has not been spread and a cut tendon, regardless of location, is an invitation for a large silk suture. The so-called "silkoma" which results could not possibly glide through the narrow pulley and a mass of local scar tissue forms which includes tendons, suture material and the pulley. Often this mass in itself is large enough to inhibit the normal blood supply to the end of the finger. From a practical point of view, "no man's land" extends beyond the pulleys and repairs will adhere if a tendon excursion carries the suture line in the close proximity of the pulley. If the distal stump contacts the pulley when fully flexed, the suture line should be advanced distally. When the laceration is in the palm, the suture line must free the palmar pulley when the finger is fully extended. A laceration in this area is usually an indication for primary closure of the wound and a secondary repair which will require a graft.



1 2

FIGS. 1 and 2. Illustrating ischemia of the finger with marked atrophy in cases which are not satisfactory for tendon grafting.

FIG. 3. Illustrating complete flexion and extension following primary flexor tendon graft.

The indication for doing a tendon repair requires tremendous thought and judgment as to the expected success. It is obvious many

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4 5 6

FIGS. 4 and 5. Case 2. Illustrating severe arthritis of the interphalangeal joint and finger flexion following a primary tendon graft.
FIG. 6. Direct attaching of the extensor of the thumb in a delayed case.

times that a full functioning finger cannot be expected. In severe injuries there is marked local shock at the time of the injury which is manifested by considerable secondary atrophy and can later be observed by a large ridge on the nail which progresses distally as the nail grows. Later we may have a secondary finger ischemia which is the result of a deep or crushing wound which involves the nerves and vessels as well as the tendons. The skin of the finger of this type is shiny and smooth. (Figs. 1 and 2.) There is marked atrophy of the pulp and a tendency for the nail to be curved. The vitality of a finger so severely damaged is not adequate to warrant tendon repair, and arthrodesing or tenodesing the joint in a position of function or amputation should be the procedure of choice. Tendons and tendon grafts do not glide well beneath a flap which has been placed on the finger because of the deep scarring and loss of soft tissue. The tissue must be soft and pliable and there should be no areas which are constricted by cicatrix.

In an occasional selected case in which the hands are clean when the laceration occurs and it has been caused by a clean, sharp-cutting instrument, a primary tendon graft is indicated. In the present day of atraumatic surgery and with the aid of antibiotics, I have found primary grafting to be satisfactory as illustrated in Cases 1 and 2. (Figs. 3, 4 and 5.) The advantages of doing a graft at the time of injury are twofold: First, there is no scarring present and the pulleys are not collapsed. Also, the muscle is not atrophied and motion can be restored after a three-week period of immobilization.

A profundus tendon or the long flexor of the thumb, if evulsed from its distal attachment or if lacerated near the attachment, may be repaired as long as four to six weeks after injury. This repair can be directly to the bone or the stump of the tendon and the only contraindication is the inability to bring the tendon down without too much tension as the result of secondary shortening. (Fig. 6). Delayed repairs of tendons in the palm must be guided by the amount of local scar and the shrinkage of the proximal tendon. We will find more separation in the palm than in the fingers, as the vincula tends to hold the tendon in the sheath when the laceration is in the distal portion of the finger. In doing delayed repairs in the palm it is advisable to put the distal tendon through an active range of motion to break up local adhesions which have formed and which will later hamper mobilization of the tendon. It is also

7 8

FIGS. 7 and 8. Case 3. Function restored to the extensor mechanism of the distal joint by use of a small tendon graft.

FIG. 9. Illustrating the deformity in a neglected case of evulsion of the distal extensor tendon and a portion of the bone.

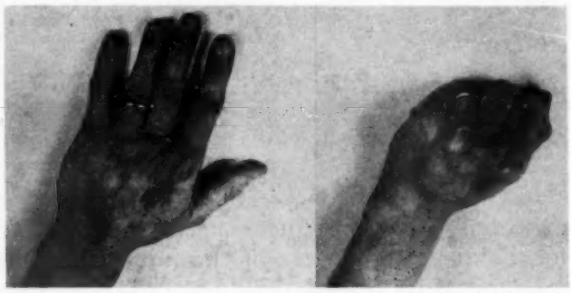

FIG. 10. Case requiring extensor graft at the metacarpal phalangeal joint.

frequently desirable to resect the distal portion of the sublimus tendon.

Primary repairs on the dorsum of the hand and fingers are, as a rule, very encouraging. The delayed repairs may be hampered by scarring and limited soft tissue and skin locally making a repair without tension almost impossible. In neglected cases of tendon lacerations on the dorsum or in old "baseball fingers" the tendon usually is united by scar which is lengthened to the degree that it will not adequately control the joint. Because of this, it is necessary to remove the scar tissue and reattach the tendon distally. I prefer using the pull-out wire technic unless there is adequate length to the distal stump; then a direct end-to-end suturing is advisable. Occasionally, in old lacerations which have gone sufficiently long, there is enough contracture of the tendon so that a graft will be required as illustrated in Case 3. (Figs. 7 and 8.) In a proximal fracture of the distal tendon attachment it is desirable to do an open operation as early as possible to replace the fragment and thus prevent anterior subluxation of the distal joint, as illustrated in the x-ray of a neglected case. (Fig. 9.)

A rupture or division of the central slip of the tendon over the proximal interphalangeal joint offers a more severe problem. If the tendon ends are not retracted, an end-to-end suture may be possible and, if so, this will restore a very useful functioning tendon. If it is impossible to bring the proximal fragment of the tendon to the distal stump, a graft is indicated. I have found the type of graft described by Fowler as being the most satisfactory. This requires placing the graft through the proximal tendon attachment, crossing it over the joint and fixing it on either side of the finger to the intrinsic muscle tendons. Elevation of the lateral tendon bands which control the distal joint to the dorsum of the middle finger is not

11 12

FIG. 11. End results of a graft to the extensor pollicus longus, with the tendon being brought subcutaneously.
FIG. 12. An end result of graft restoring the extensor carpi ulnaris tendon.

desirable as you lose the control of the distal joint. Lacerations in the region of the proximal joint should be repaired on the lateral and medial side as well as the dorsum to re-establish the extensor sleeve mechanism. By restoring the extensor sleeve, the intrinsic control of the finger is maintained, which prevents the tendon from dislocating off the head of the metacarpal and thus failing to produce full extension. It may be necessary to put in a graft in this area if the tendon ends cannot be approximated without tension. Any tension would tend to prevent full extension of the other fingers as the tendons have a common origin. This is illustrated in Figure 10 in which a graft was necessary. In a delayed repair of the long extensor of the thumb or the extensor carpi ulnaris it is very frequently necessary to use a tendon graft. In this situation, it is desirable to bring the tendon graft subcutaneously so that the constricting sheaths will be avoided. (Figs. 11 and 12.)

SUMMARY

It is usually desirable to delay tendon repair in the region of so-called "no man's land." Occasionally a primary graft may be done in this region. A tendon graft is frequently necessary on the dorsum of the finger at the level of the distal, medial and proximal joints. A severely scarred finger is a contraindication for delayed tendon repair.

CRUSHING WOUNDS OF THE HAND

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CRUSHING wounds of the hand represent a complex type of injury for damage may involve the covering structures, muscles, bones and tendons. Crushing wounds combine all factors which are found in both the closed or open type of injury.

There are many types and varieties of crushing wounds. These wounds may be closed or may be open and compound. The amputated finger tip is a common crushing injury. The closed type of wound is best illustrated in the wringer injury with marked subcutaneous hemorrhage and severe trauma to the skin and subcutaneous tissues. The open crushing injury is the result of the hand caught between rollers or injured in a punch press, and here there are compound fractures, division and fraying of the tendons, contusion to the nerves and tearing and mutilation of the skin and subcutaneous tissues.

The diagnosis of a crushing injury is apparent from the history and is confirmed by the character and appearance of the wound. In the open type of injury there is invariably irregular, jagged edges to the skin and subcutaneous tissue wounds and this type is frequently associated with fractures, with or without tendon damage. In the diagnosis it must be realized that profound swelling, which occurs almost immediately to the hand, is the result of the subcutaneous hemorrhage and later the edema which so characterizes these injuries.

As to the treatment of crushing injuries the first aid should be simple and its objective should be to protect and prevent further mechanical and infectious trauma from being added to the wound. The surgeon's objective for the crushing injury, as in any wound, is to convert the open wound into a closed wound. Where immediate definitive care can be provided, the immediate operation is often all that may be required, and the secondary, reconstructive operations are not necessary. However, to accomplish this the surgeon must take care that all structures are correctly reduced and the wound heals per primam. The surgeon must exercise every care to see that there is no delay in healing. Delay in healing of these crushed wounds results from forgetting the pathologic condition which is marked in these injuries. The trauma to the soft parts is very great and there is a tendency for the skin and subcutaneous tissues to heal poorly and this often means continued drainage, prolonged immobilization and late fixation of the hand. One of the more common errors is the practice of taking the torn, mutilated flaps of skin and subcutaneous tissues and either placing them back into position without adequate excision or excise them and then suture them under tension. Either of these procedures will produce an error which will always delay healing.

It may not be out of place to comment briefly on the treatment for amputated finger tips. This injury is simply a smaller form of more extensively crushed hands; but just because it is a small wound is no reason it should not be closed with care. Usually this injury can be dealt with and treated in the outpatient operating room. The entire hand and forearm is carefully cleansed; the wound is carefully flushed and irrigated. Local anesthesia is infiltrated in the volar aspect of the forearm for a potential skin donor area and the tip of the digit is then anesthetized. A bloodless field is obtained by the use of a blood pressure cuff. After anesthesia is obtained, the amputated tip is carefully excised of all devitalized tissue, all irregular bits of skin and occasionally small chips of bone. In most injuries of this type the trauma has produced an amputation of the bone at the same level as the soft parts, but occasionally the tip of the bone may protrude 1 or 2 mm. When this has occurred, this bone is cut away to the level of the soft parts. After bleeding is controlled, a thin layer of adjacent subcutaneous tissue is drawn over the exposed bone, and a small, postage-stamp size split-thickness graft is removed from the forearm site and is carefully sutured into place with tie-over sutures. Then a pressure dressing and splint are added. This type of graft has been

satisfactory as a final type of tissue for use. Of course, when the thumb or index finger has been amputated, we are prone to use a primary pedicle flap taken from the chest wall or abdominal wall. The indication for the use of the pedicle flap, however, is best shown when bone is still intact but the cap of subcutaneous tissue has been torn away. Naturally, we are very reluctant to see further amputation to the vitally important thumb and index finger.

If the amputation has been proximal to the distal interphalangeal joint, the digital nerves must be carefully identified, drawn into the wound and amputated high to prevent their inclusion in the final scar. It is also important never to suture the flexor and extensor tendons over the amputated stump for this always results in a limitation of motion of the digit. Finally, we see no reason to amputate at certain sites to produce a cosmetic result in an acute trauma because we believe that all length possible should be salvaged and saved. If necessary, corrective reconstructive procedures may be carried out later but it is surprising how seldom this is indicated.

The closed type of crushing wound to the hand is a common injury occurring both in the home and in industry. Perhaps its most usual source is where the hand is caught in the rollers of a wringer. When first seen, these closed injuries do not reveal much gross disturbance for there is minimal swelling and the x-ray is usually negative, but occasionally a green-stick type fracture may be observed. However, from the history of the injury it is imperative that the surgeon realize the usual sequelae are hemorrhage in the skin and subcutaneous tissue, marked late swelling of the hand and even, in some, gangrene of the skin of the dorsum of the hand. When possible to treat these closed injuries early, our practice has been to wash the hand carefully and apply an evenly distributed pressure dressing with the hand immobilized in a position of function on a universal splint. If this precaution is not taken, the hand becomes greatly swollen and disability can become very real for hemorrhage soon fixes and immobilizes the tendons and small joints of the hand. We have not followed the practice of aspiration of subcutaneous hemorrhage because, in our opinion, this hemorrhage is usually distributed throughout all layers and seldom is ever a single collection of blood. Further, it is not without danger to cut through such an area for drainage since this recently traumatized skin may exhibit delay in healing, and the introduction of a potential infection into this traumatized area is a very real factor. It is seen that the most efficient and practical manner is to apply a pressure dressing early to prevent the hemorrhage and subsequent edema from becoming fixed. This immobilization is used for five to seven days. When late necrosis of the skin on the dorsum of the hand becomes apparent, its management requires immediate excision of all of the obviously necrotic skin and replacement with split-thickness skin grafts to produce the closed type of wound. After sound healing has occurred, replacement with more satisfactory tissue may be indicated.

The open crushing injury is a true compound wound, with involvement of the skin, bones, joints and tendons. The most common type of injury is that with severe tearing of the skin and subcutaneous tissues with a distally attached flap, as when the hand is forcefully withdrawn from between rollers or other such machines used in industry. There frequently is tearing and fraying of the tendons and nerves, joint capsules, associated fractures of the bones or even amputations of parts of the digits. Such wounding presents a formidable problem; however, even though it is complex, the principles of care are the same, namely, to free the wound of all devitalized tissue, to see that the wound is carefully closed and that primary healing is obtained.

To handle such an injury adequately, the main operating room should be employed, where all possible precautions can be taken to prevent infection and where proper instruments and general anesthesia are available. Under general anesthesia and with the use of a blood pressure cuff, the hand and surrounding parts are carefully cleansed. The blood pressure cuff is always applied but in a few examples it has not been employed, particularly when it has been our belief that either the slight or temporary occlusion of the circulating blood may influence the viability of the tissues. When this has been probable, we have not employed the blood pressure cuff. Fortunately these have been rare and in the great majority of cases we have used the blood pressure cuff in a routine manner to obtain a bloodless field.

The surgeon is now confronted with the problem of how much to excise and, as Mason has stated, this requires wisdom and courage; wis-

dom to know what and how much to excise and courage to excise that which must be sacrificed. It is very difficult to state definitely how much skin and subcutaneous tissues should be removed when the surgeon is confronted with these tearing, lacerating type of injuries. It is well known that crushed tissue will not survive if it is simply sutured into place. Under accurate vision and a bloodless field, the surgeon must excise all tissue which is non-viable and this means the excision must go back and up to the healthy bleeding tissues. The surgeon must remove that skin which is pale and bloodless and frequently there are such areas scattered throughout the palm and dorsal aspect of a crushed hand.

The amount of excision necessary to muscles is not as difficult to determine, for that follows the usual criteria of contractility, bleeding and general appearance. The amount of excision which is indicated for tendons should be minimal and the same certainly applies to removal of any nerve tissue, except where the nerve should be highly amputated to avoid the inclusion of the neuroma into the final wound. The amount of removal indicated for bone and joint tissue is easy to determine for anything which has attachment should be preserved. Regardless of how severely comminuted the bone and the joint may appear, it should not be unwisely sacrificed, for it is amazing how these injuries can be molded into place and can be restored to a functioning hand.

After satisfactory excision has been performed, gentle pressure is applied to the wound, the blood pressure cuff is released and all bleeding points are ligated. In such crushing injuries we have started by closure of the volar wound, which is usually the most minimal. The hand is then placed on a sterile, universal splint and we proceed with the reduction and closure of the deeper tissues from the dorsal aspect. Injuries to the joints can be carefully closed and the compound fractures may be aligned under vision and reduced by molding over the universal splint. In rare instances the nerves may be sutured but, on the whole, this is seldom required in a crushing type of injury at this time. It has not been our practice to suture the flexor tendons in the presence of a compound fracture of the phalanges, for too often the flexor tendon callus and the bone callus become united into one single mass. It is a better practice to reduce the fracture and close the open wound and, when osseous healing has become firm, then proceed with a flexor tendon graft. The extensor tendons, however, can often be successfully sutured in the presence of a compound fracture at the same level of the wound.

After the deeper structures have been aligned and reduced, the surgeon is confronted with the problem of closure of the covering tissue, and here it requires considerable ingenuity to obtain adequate reduction of the fracture and closure of the skin and subcutaneous tissues. Certainly the surgeon cannot simply close skin and ignore the fracture nor can he reduce the fracture and ignore the covering skin, for both procedures will lead to disability and failure of proper healing. Closure of the skin and subcutaneous tissue is not easily obtained. As stated before, tension must be avoided for this will result in delay in healing and will leave exposed bones, tendons and joints which could drain for weeks to months and result in the typical thick, stiff, immobilized hand. However, in a few cases simple suture may be obtained, but in the vast majority of crushing injuries closure must be accomplished by incomplete suturing of the soft parts up to the point that tension is necessary to effect further closure. This results in a residual wound, and this must be covered with a split-thickness skin graft, taken either from the same forearm or from the thigh. This skin dressing will give a closed type of wound. Such skin grafts can survive over bone and tendon, but it is better to plan to shift adjacent skin and subcutaneous tissues to cover exposed bone and tendon and the split skin grafts placed over the less important areas. This method of closure may be used in many occasions but it is imperative that the flaps of skin and subcutaneous tissue be broad in outline and the flaps thick so that the viability of this tissue may be insured. The final method is the employment of a primary pedicle flap from the lower chest wall or the abdominal wall. In most instances this is not feasible in the presence of compound fractures; however, its use has been successfully employed where the soft parts only are involved. Before undertaking such a procedure the surgeon must be aware of the technical problem of maintaining immobilization and pressure.

After the fractures have been reduced and the wound is closed, a large, resilient pressure dressing is applied. This has a very real purpose and its use is directed to prevent the accumula-

tion of blood and later edema into the subcutaneous tissues, to occlude all dead spaces and particularly to aid in the return of the venous circulation in the flaps of tissue which have been created by the injury. Most of the flaps of tissue which have died have usually drowned due to venous congestion, for seldom has it been an arterial problem if correct excision has been employed. The pressure dressing has been beneficial in maintaining the venous return from these mutilated pedicle flaps.

In general, the treatment of fractures has not been a difficult problem since the employment of the universal splint. This method of handling fractures of the hand, whether simple or compound, has resolved itself into correct and accurate reduction under general anesthesia immediately, and immobilization and maintenance of reduction over the universal splint in position of function by the use of a large, pressure dressing. This method has minimized the post traumatic edema and has satisfactorily held all fractures, including oblique fractures, in adequate reduction. Traction in any form, has not been used since the introduction of the universal splint.

Occasionally, the surgeon is confronted with a severely mutilated hand with partial amputation of all of the digits and loss of the tissues on both the volar and dorsal aspect. We have not followed the thought of amputation at the level of the wrist for such serious traumas. Rather, we have believed that it is important to save all viable tissue and obtain closure of the wound by one of the many methods as previously outlined. Surely, even these stumps of hand can be used and late reconstruction can be employed with benefit to the patient. Even a stump of a hand is more efficient than the best of prostheses.

The follow-up care of these crushing injuries may involve late tendon repair and further replacement of the thin, split-thickness grafts which were used as a simple expedient to provide a closed type of wound. Often, grafts of more suitable types of tissue may be indicated at a later date.

Crushing injuries have a different prognosis from a sharply lacerated wound with division of nerves and tendons. The crushing injury often shows delay in healing. Infection has a higher incidence in these cases than in other types of injuries. Also, the post-traumatic edema is seen often unless one is alert to prevent hemorrhage and reduce its complications by the use of pressure dressings. Finally, the disability of the hand is greatly increased in a crushing injury and the length of time to return to full function is always prolonged.

In all these cases of crushing injuries of the more severe type, tetanus antitoxin or toxoid as indicated have been used. The antibiotics have been used routinely in this type of injury as contrasted to their indication in a sharply lacerated wound.

CONCLUSIONS

It is imperative that surgeons realize the importance of conversion of open wounds into closed wounds regardless of the number of structures of the hand involved.

The hand is a functioning unit, and it is necessary that the treatment be directed intelligently to repair of bone, tendon and covering tissue. No tissue can be ignored at the expense of another. To accomplish results which are satisfactory to the patient, it is imperative that the principles of traumatic surgery be realized and followed accordingly. Crushing wounds of the hands represent a very complex problem which must be approached with a definite plan of therapy.

ACUTE BURNS OF THE HAND

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IN presenting the subject of burns of the hand we wish to submit the problem for consideration and discussion, rather than a report of facts ascertained and results accomplished. This problem is an old one and has been given thoughtful study and serious consideration by numerous men.[1–14]

The hands comprise only 4½ per cent of the total body surface area, yet the future of the patient with burned hands often depends upon the type of initial treatment and resourcefulness of the personnel designated to treat his injuries. Too frequently the patient, because of the apparent emergency, will accept the ministrations of anyone, from corner druggist to the local sanicultist. The tragedy of the secondarily infected hand is a familiar one to surgeons. Healing complicated by edema and infection is often slow and tedious resulting in retraction, sclerosis of tendons and ankylosis of joints. The delicate balance between the tendons, muscles and nerve endings responsible for coordinate motion and sensory perception will lead to considerable functional disability seriously affecting the earning power of the individual.

Burns cause damage from without-inward, sparing well protected vital structures. On the palmar surface the fascial covering overlying the tendons, blood vessels and nerves will often protect these structures against severe injury. Should the burn involve the flexor tendons, serious prognosis for the involved hand or digits will exist. The dorsal tendons are not infrequently involved in a sloughing process. The dorsal vessels are more prone to injury and subsequent necrosis than are the volar channels. In the fingers the digital collaterals, if subjected to high temperatures, become thrombosed and result in ischemic gangrene. Infection extending into joints will invariably result in a useless stiff digit. Sclerosis and retraction of tendons may dislocate the metacarpophalangeal joint, claw the hand or, because of contracting keloid, extend the wrist and limit function of fingers. (Fig. 1.) Malpositions of burned hands are better prevented than corrected by purposeful splinting during the various phases of healing.

In considering the patient with burned hands we shall restrict our discussion to the treatment of the local condition. Extensive burns of the hands are usually associated with burns elsewhere on the body. In those patients in whom shock is impending or has ensued, local therapy and general management are carried out simultaneously.[3] The patient with an uncomplicated hand burn shows little or no evidence of shock or hemoconcentration. Nevertheless protein, vitamin, hemoglobin and electrolyte levels should be determined and depletions corrected in order to obtain more rapid healing of burns and their subsequent grafts.[3]

The inciting agents of burns of the hand, as elsewhere on the body, are: (1) thermal: flame, hot water, freezing; (2) chemicals; (3) electrical and (4) radiation. The distinguishing features and treatment of burns caused by these agents will be discussed herein.

The objective in successful local therapy of the burned hand is to obtain rapid healing, and maximal return of function in the earliest possible time. The management is divided into (1) the initial phase and (2) the late phase. In the initial phase the objectives are (1) to control pain, (2) to protect the hand against further tissue destruction as results from added bacterial, chemical or mechanical trauma and (3) to prevent the development of edema. In the late phase we are concerned with (1) the removal of slough, (2) the obtaining of rapid healing and skin coverage and (3) the prevention of contractures.

Control of Pain. With these localized burns adequate doses of opiates will usually suffice to allay pain. If the room is kept free from drafts and warm and the wound gently washed with soft cotton and warm solution, very few patients, even the very young, complain of pain.[3] Allen and Crossman[15] prefer cool water for washing as they feel that relief of pain is better obtained in this manner. The rapid application of a dressing will allay pain very effectively.

Many of these patients are actually more restless than in pain and can be controlled by adequate doses of barbiturates combined with small doses of codeine if necessary. Intravenous procaine hydrochloride, 0.1 per cent, likewise has been used for relief of pain.

Protection of the Hand against Added Trauma. Additional Bacterial Contamination: It is essential that the general public, first aid crews and physicians be informed of the dangers of talking, sneezing, laughing, etc., in the presence of an exposed wound.[7,16] The immediate masking of all personnel including the patient, or the immediate covering of the burn itself with a sterile towel or sheet will serve adequately to exclude virulent bacteria from settling out on the burn. Should sterile sheets or towels not be available, it is best to use the cleanest covering available. One must evaluate the dangers of air and droplet contamination as compared with that of the cleanest covering available and choose the lesser evil.[7] This covering should be applied immediately, for the greater the exposure time and surface area damaged, the greater will be the number of bacteria that settle on a given surface.[7] Burned hands, comprising one twentieth of body surface, have ten times as much air contamination hazard per minute as an ordinary appendectomy wound. Brown[7] believes that it is safer to perform an appendectomy without masks than to dress a burn with the nose and mouth exposed. After the immediate covering of the burn it is not exposed except under conditions of strict asepsis. The administration of tetanus antitoxin or the toxoid is routine with all burns of 5 per cent of body surface. Localized burns heavily contaminated with street dirt and of lesser surface area are advisedly treated with tetanus antitoxin. The immediate administration of antibiotic drugs and their continued use in adequate dosage will further protect against invasive infection. The appearance of healthy granulation offers increasing protection against infection. In patients sensitive to penicillin we have utilized the sulfonamide preparations and aureomycin.

Injury by Chemicals: It is not uncommon to find various chemicals on burns, these having been rashly applied in the hope that they would exclude infection and relieve pain. These magic drugs have been of little use; in fact, they are more often deleterious to healing. There has been a shift of emphasis from local sulfonamides, penicillin ointments, triple dyes and tannic acid to the simple occlusive dressing.

FIG. 1. Severe contracture of hand in a twenty-three year old woman. She suffered severe burns of her hand at the age of eighteen months.

Added Mechanical Trauma: Protection against additional trauma is best obtained by gentleness in débridement and washing, followed by splinting of the hand in position of function after application of pressure dressing.

TREATMENT

There are several schools of thought with respect to local management. Some men will do no débridement or washing[8,15] believing that the burn has adequately sterilized the part. Mason[3] believes that surgical sterilization is a more elaborate process than just momentary exposure to heat. Lam[14] states that there is rarely need for much débridement and vigorous washing and is of the opinion that scrubbing adds to initial injury and aggravates loss of red cells, plasma, etc. Meleny[17] has shown that infection is two times as frequent in wounds with maximal washing as with minimal washing. We have followed the dictates of Koch, Mason and Allen in respect to initial treatment of these burns; that is, under strict asepsis of masking, gowning, use of gloves and sterile drapes the fresh burn is converted into a surgically clean surface by washing with bland bar soap and water and irrigating with saline solution. The devitalized shredded skin is excised. Small

blisters are left intact while the larger ones, because of the discomfort entailed by their presence, are punctured after cleansing and permitted to collapse. Whenever possible the blisters are permitted to remain unopened as the plasma bathing the underlying burn is an ideal dressing. If both hands are involved in the burn process, it is less shocking to have them simultaneously prepared for application of an occlusive dressing.

The treatment of chemical burns as well as electrical burns is essentially the same as for thermal burns. Washing of chemical burns is preferable to neutralization since the latter process generates heat and will cause further damage to already injured tissues.[18] Phosphorus will continue to burn unless air is excluded by wet dressing. The phosphorus should be removed with gauze-covered forceps. The treatment then becomes that of thermal burns.

Application of Occlusive Dressing. The objectives of this dressing are threefold: (1) To exclude further contamination; (2) to limit local plasma loss and (3) to maintain the hand in position of function.

Since the hands comprise only a limited body surface area, the external losses through the burned surface are of least importance. Harkins[19] and Glenn[20] have demonstrated the considerable loss of fluid into the subcutaneous tissues in deep burns and state that it may surpass the external losses. The elastic pressure dressing as described by Allen and Koch[1] is the most satisfactory method in use today for prevention of edema. This aided by elevation of the part will serve to control swelling. The drainage of lymph and venous blood by gravity, thereby relieving stasis, will improve local circulation and aid healing.

Materials required for occlusive pressure dressings are: (1) cotton glove, impregnated with vaseline; (2) fine mesh gauze, with or without vaseline; (3) mechanics waste; (4) fluff gauze; (5) universal hand splint of Mason and Allen and (6) Ace bandages.

Technic of Application. After preparation of the hand under aseptic conditions, the fingers are individualized with strips of fine mesh gauze or vaseline-impregnated cotton glove. A relatively easy and rapid method of individualization of the burned fingers was recently described by Boethe and Kerr.[21] Fingers are rapidly and painlessly individualized by the application of a vaseline-impregnated cotton glove. If gloves are not available, strips of gauze are placed longitudinally so as to offer the least possibility for constriction of digital circulation. (Figs. 2A, B, C and D.) To eliminate the constricting effect of the glove as edema develops we have split the glove over the dorsum of fingers, hand and wrist. Flat, dry sponges are placed over the mesh gauze. Over this layer is placed fluff gauze, mechanics waste or foam rubber. The entire hand is splinted in position of function on a universal splint maintained with elastic bandage. It is essential that the dressing be placed well above and below the area of burn in order to minimize proximal or distal swelling. Should seepage occur during the course of healing, the entire dressing is reinforced and an Ace bandage is again used to maintain constant pressure. Owens[22] has suggested the use of cellophane membrane around the pressure dressing in order to prevent contamination which may occur with seepage.

Post-operative Care. It is essential that the patient with burned hands be given every assistance toward recovery. This will entail care of his nutrition, body hygiene and elimination. Persons with bilateral burns are rather helpless; they are also impatient to have their fingers released so that they will be able to care for themselves. The use of the vaseline-impregnated glove simply wrapped in sterile towel, as described by Boethe and Kerr,[21] is of great help in this respect during the later convalescence of the second degree burn only.

It is essential that the patient be informed of the reasons for neglect of the burn dressing; namely, the dangers of injuring delicate advancing new skin[23,34] and the discomforts of pain incurred by frequent changes. Masterful inactivity will heal more burns than meddlesome curiosity. Unless evidence of sepsis occurs the first dressing is not disturbed until the tenth to fourteenth day. At the end of this time most dermal burns are found to be healed and will require no further dressings. The deeper burns, however, will require additional treatment. Many second degree burns well on the way toward healing will heal under reapplication of a pressure dressing for several additional days, and will by the end of three weeks be completely healed. Boethe and Kerr simply apply vaseline glove and place a sterile towel over this dressing. This is removed twice daily and the hand placed in saline water bath for thirty minutes twice daily until healing has occurred.

FIG. 2. A, the burned hand is dressed with vaseline gauze on a universal splint; B, fluff or waste material are placed beneath the hand; C, dressings are then placed completely around the hand; D, elastic bandage is then used to wrap the hand in pressure.

The initial postoperative dressing as well as subsequent dressings are done under aseptic technic. Anesthesia is usually not necessary. Sedation, such as morphine, will suffice. The third degree burns will be covered with slough in various stages of demarcation. All visible, loosely attached slough is excised after gentle irrigation and pressure dressing is reapplied. The dressing is then changed every second to third day depending on depth and attachment of slough. Under this regimen all but the very deep sloughs are removed in seven to ten days, and the area ready for grafting within three weeks. The very deep slough which usually is slow to separate is excised under anesthesia and pressure dressing reapplied. Three to five days later if on inspection the granulating bed is clean, split-thickness skin grafts are applied. With each dressing and irrigation the patient is encouraged to flex and extend the finger and wrist joints actively.

We have no experience with chemical methods of débridement. Many observers report that pyruvic acid is painful when first applied and the time gained does not seem to warrant its use in preference to compression dressing.

Cope et al.[25] have carried out delayed excision and skin grafting in burns more generally distributed, the excision being done three to seven days after the burn was incurred and a graft immediately applied. Ackerman and his associates[26] have utilized the same procedure after ten to fourteen days. Primary excision of the burned area has a limited place in the treatment of the hand injured by heat. There are no reliable tests for differentiating second from third degree burns. The dangers of excising viable vital tissue in the hand are great.

Prevention of Contractures. The prevention of contractures is the primary aim in all burn treatment and begins with the first aid treatment, directed against those factors which increase fibrosis and malpositions, namely, infection, edema, failure of protection against vicious positions and failure to obtain early skin coverage.

The primary goal in full thickness burns is

skin coverage as soon as slough has separated. Burns over and adjacent to joints should be grafted as early as possible in order to prevent and minimize crippling. The split-thickness graft is most serviceable for average burns and should be applied to well vascularized pink granulations. Not infrequently the split-thickness graft will break down when subjected to undue motion and pressure and will have to be replaced, but the treatment of such defects comes under the realm of plastic reconstructive surgery and does not come into the scope of our present discussion.

Physiotherapy. Active and passive motion must necessarily be delayed during the period of graft healing, but should be resumed as soon as healing has occurred. During the pre-grafting period active motion under sterile hand baths should be encouraged after the first dressing has been removed. All uninvolved digits should be mobilized as early as possible. The use of knuckle bender splints, cock-up splints, splints protecting hands against clawing and thumb web contractures is essential to early restoration of uninhibited function.

Burns from Electricity. Unlike thermal burns, burns from electricity are usually painless, sharply demarcated and show little tendency toward inflammatory reaction and vesicle formation. Healing is slow; the burn usually remains rather indolent for many days to weeks and slough will finally present over an area much larger than that initially observed. Hemorrhage, sudden and profuse, resulting from necrosis of radial and ulnar arteries is not uncommon. Martin et al.[27] and Jelinek[28] believe that this is a result of disintegration of the media of arteries; brittleness and friability of vessel walls occur with subsequent perforation and hemorrhage.

Radiation Burns. Unlike the thermal burn which, if properly treated will be completely resolved within a few weeks to months, the radiation burn presents a continuing problem. A previously reported excellent physiologic and cosmetic result not infrequently presents with either a late necrogenic dermatitis or malignant transformation at the site of the previous injury.

The hands are most frequently involved in this injury because of their exposed positions. Teloh, Mason and Wheelock[29] biopsied 132 lesions involving the fingers, the palmar and dorsal surfaces of the hand and the wrist. These specimens were removed from 121 patients; an additional eighty-three specimens were removed from other parts of the body. Whereas in the past the roentgenologist because of either ignorance or disregard for his welfare was the most frequent victim of his occupation, today the industrial worker and commercial epilator, dentist, radiotherapist, surgeon and atomic researchers fall prey to undesirable effects of x-ray and radium.

Radiation burns like thermal burns may be of three degrees. The acute burn seen as a result of atomic energy exposure to 12,000 r for a few seconds will result in a sloughing third degree burn in contrast to the burns of repeated x-ray exposure with transient erythema noted within twenty-four hours after exposure to beta and gamma rays. Blistering may occur in four to six days and runs its course in about one month at which time either healing or ulceration may be noted.[30] In severe reactions loss of hair will occur. When healing occurs after several months, the residum of a second degree burn may be a hyperpigmented area. This type of burn, namely, second degree, is invariably followed in an average of fifteen years by development of malignancy. The first degree burn may leave the skin atrophic, then smooth, glistening and dry, the latter resulting from decreased sebaceous secretions due to destruction of adnexal glands.[29] In later stages hyperkeratosis appear and telangiectasis may be noted.

The third degree burn is characterized by redness, swelling and exudation and associated with excruciating pain. Slough and ulceration is the rule. Necrosis of the underlying structures such as bone and tendon may occur either early or late, necessitating wide excision or amputation.

The treatment of radiation burns of the hands should be conservative. As soon as minute ulcerations occur, Brown[30] advises "changing of skin" in an involved area before serious trouble develops. Since deep burns of hand usually have impaired circulation, it is essential that at least one artery be maintained and either the palmar or dorsal surface grafted at one sitting. When circulatory impairment is known to exist, isolated keratoses are removed and allowed to heal individually. These fingers which are hopeless from a functional standpoint should be removed.

3A 3B

FIG. 3. A, severe first and second degree burns of both hands. B, at the first dressing fourteen days later the fingers and hand were débrided.

The local care of the burn consists essentially of the application of a dressing with moderate pressure. As soon as demarcation occurs excision should be done well beyond the margins of reaction and split-thickness grafts applied. All slough should be excised. Daily dressings and daily removal of slough will hasten the demarcation process. Removal of the ulcerated keratotic lesion which is very often quite painful is the best means of solving the problem of pain. Control of pain will often necessitate small doses of morphine. The survival of grafts depends upon local circulation. Often the deeper circulation is involved and free grrfts will not "take." Furthermore the need for excision of vital structures and their blood supply may necessitate a pedicle or flap graft.

The permanance of the result cannot be guaranteed. Many patients will retain function and skin integrity for years after repair of severe burns. Occasionally, secondary excision and repair because of surrounding tissue changes occurring several years later will be needed. If carcinoma has developed in a radiation burn, excision of this lesion either with or without preoperative irradiation must be carried out.

Frostbite. The treatment of frostbite of the hands is similar to that of burns. Three classifications are described in the literature. First degree frostbite consists of swelling, redness and an increased temperature. In more severe cases blebs may result. In second degree frostbite there is dry gangrene involving the distalmost portions of the extremities. When extensive gangrene involving more proximal portions of the extremity occurs, third degree frostbite is recognized.[31]

The pathologic changes are due to vasomotor changes and those due to the actual freezing of the blood, so-called humerol pathologic changes. In regard to the vasomotor changes there is constriction of the vessels so that eventually no oxygen reaches the capillaries and the skin becomes cyanotic.

The treatment of the frostbitten patient consists first in the treatment of the patient as a whole. If severe freezing occurred, shock must be combated with fluids, plasma and whole blood. Hot stimulants such as coffee and even alcohol are suggested. The local treatment should consist first of gradually warming the affected extremity to room temperature. Gentle fanning at 75° to 85° is advised.[33]

Rubbing with snow is not advised because of the danger of infection and because of more injury to the already damaged tissue.[34] Gentle cleansing such as that in a burn may be done. Pressure dressings are then applied. Nupercaine ointment may be used for analgesic purposes, otherwise vaseline gauze may be used.

Cervical sympathetic blocks may be used for frostbite of the upper extremity. This was suggested by Penberthy[35] in 1943 and has been used frequently in the treatment of frostbite.

The use of heparin in frostbite should be considered. The treatment of experimental human frostbite was first described in 1945. Those patients who received heparin suffered less injury and necrosis than those who did not.[36–38]

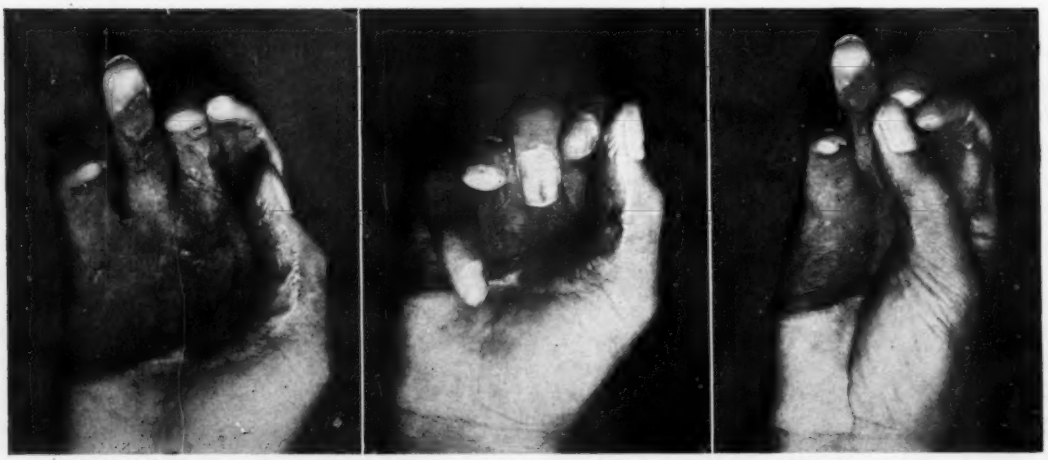
Amputation of the affected member is done late because the first line of demarcation may be deceiving. Viable tissue often appears distant to the original darkened area.

3C 3D 3E

FIG. 3. C, D and E, excellent function five weeks after the original burn.

4A 4B 4C

FIG. 4. A, twelve day old severe third degree burn of practically the entire palm of the right hand. B, granulation tissue present at nineteen days; C, involved area covered with a split-thickness skin graft.



4D 4E 4F

FIG. 4. D, E and F, palm is well covered. There is some restriction of motion but a fairly good functioning hand has been obtained.

CASE REPORTS

The following is a case report of the most common type of first and second degree burns of the hand:

CASE I. E. H., a forty-six year old colored male, was admitted to the City of Detroit Receiving Hospital on April 23, 1950, with first, second and third degree burns of both hands incurred when he was burned with hot grease. (Fig. 3A.) Débridement was minimal and cleansing was done. Vaseline gauze pressure dressings with the hand in position of function were then applied. Penicillin was given twice weekly. The dressings were left on for fourteen days and then removed. Blisters were débrided (Fig. 3B) and the hand was redressed in vaseline gauze pressure dressing for another week. At that time there was good motion of the left hand while the right hand was slightly limited. Five weeks after the original injury (Fig. 3C, D and E) he had excellent function.

By means of a bland ointment pressure dressing and infrequent changes an excellent result with no infection was obtained.

The next case illustrates early skin covering of a severe burn of the palm:

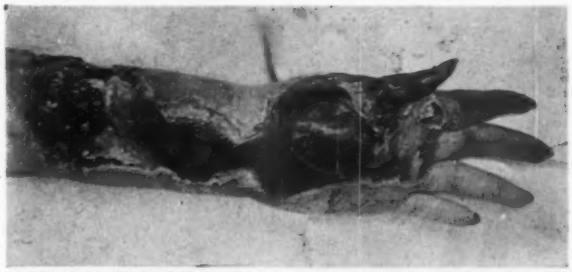


FIG. 5. Severe electrical burn of hand and forearm. Amputation was done in this case.

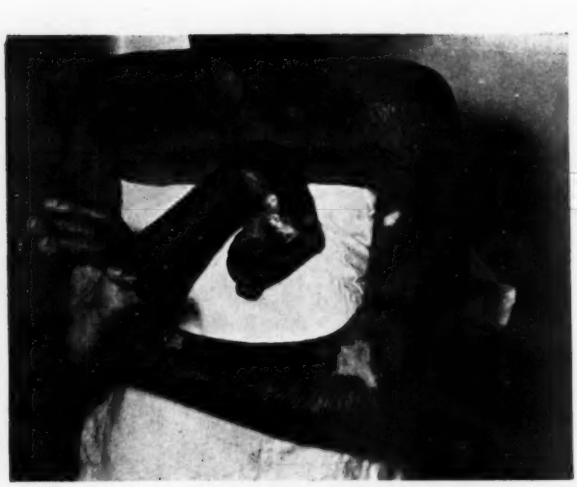
6A 6B 6C

FIG. 6. A and B, severe second degree frostbite of both hands; C, both hands in pressure dressing.

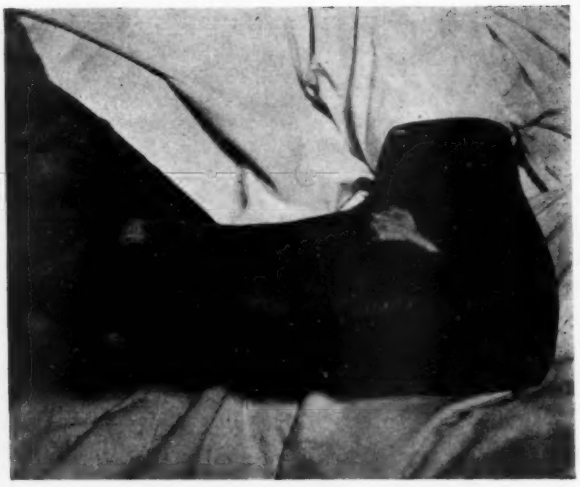
6D 6E 6F

FIG. 6. D, hands at the end of one week; blebs have been débrided and nails are beginning to slough; E and F, complete healing at the end of three and one-half weeks.

CASE II. F. P., a thirty-seven year old colored male, was admitted to the City of Detroit Receiving Hospital December 6, 1949, in an acute psychotic state. Examination revealed a third degree burn of the entire palm of the right hand. This was about five or six days old. He was placed in the mental ward. Continuous saline soaks were applied to the entire right hand. On December 12th he was taken to the operating room and under brachial block anesthesia the dead and necrotic tissues were carefully débrided. (Fig. 4A.) A pressure dressing on the universal metal splint was applied. One week later examination of the hand revealed a nice granulating area. (Fig. 4B.) These granulations were carefully shaved down with a Blair knife. Bleeding was controlled by the local application of epinephrine. By



7A



7B

7C

7D

FIG. 7, A, severe scarring from a neglected third degree burn; B, close-up of a severe contracture of left wrist; C, scar excised and hand ready to be inserted under the abdominal skin; D, hand under skin flap.

means of the Padget dermatome two drums full of skin were taken from the right thigh and sutured over the granulating area. (Fig. 4C.) However, in two days he tore this dressing off and this time it was reapplied with plaster on a universal metal splint. The first dressing was done five days later and a very good "take" of the graft was obtained. There were two small areas over the tips of the middle and ring fingers which had to be regrafted with small split-thickness grafts. The flexor digitorium profundus of the middle finger sloughed later at its insertion. Healing continued and on February 15, 1950, the patient was transferred to a nearby mental hospital. Follow-up there several months later revealed that the skin graft had taken very well but that the patient did have some limitation of motion. Because of his severe psychoses it had been impossible to give him any type of physical therapy. However, other than a slight adduction contraction of the thumb and inability to flex the right middle finger completely (Fig. 4D, E and F) he had a fairly good functional result.

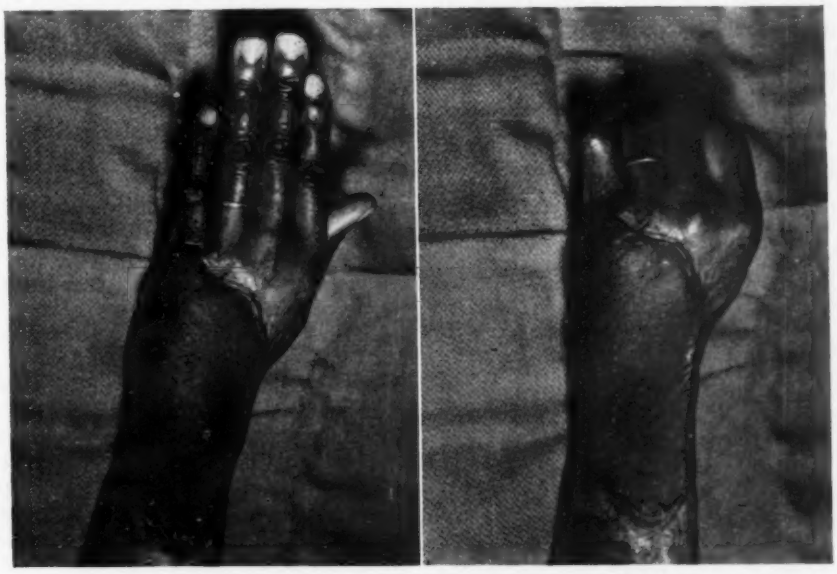
The third case is an example of a severe electrical burn:

CASE III. A. C. G., a forty year old white male lineman, was admitted to the Allentown General Hospital in a state of unconsciousness. He received

burns of chest and left hand when struck by a full charge of high tension current. The hand itself presented burns of severe degree with carbonization and mortification of the thumb and index finger as well as the thenar eminence and volar aspect of wrist and lower third of volar aspect of the forearm. The long finger was fixed in partial flexion at the middle interphalangeal joint; this digit was cold and anesthetic. Pulpification of the flexor muscles of the upper third of the forearm had occurred. (Fig. 5.)

Because of difficulty in judging actual extent of destruction the initial local treatment consisted of fine mesh gauze, voluminous dressings and immobilization in position of function. General treatment consisted in administration of O_2 and plasma. Cardiac rhythm was slightly irregular, rate 120; blood pressure 110/60. Return of consciousness and normal respiratory depth was rapid and presented little concern in this case.

7E



7F 7G

FIG. 7. E, detachment of hand from abdomen; note donor site. This was covered with a split-thickness graft. F and G, function of hand two years after application of full-thickness muff type of graft.

On the tenth day after admission moderate bleeding occurred from the volar aspect of the wrist. Attempts to control this during the night by pressure were only partially successful. Because of saturation of dressings the patient was taken to the operating room and the radial artery was ligated. Hemorrhage from the ulnar artery occurred on the twelfth day. In view of total destruction of involved flexor tendons and nerves and destruction of the major blood supply to the hand it was deemed a life-saving measure to amputate the arm. This was accomplished under pentothal anesthesia 3 inches below the elbow. The wound was permitted to heal by secondary intention. Healing was completed in nine weeks.

This case illustrates (1) the wide spread destruction caused by electrical burns; (2) difficulty in controlling hemorrhage and (3) the progressive nature of tissue damage making it rather difficult to prognosticate the outcome. The first lesion is usually greater in extent than is apparent on initial examination. Therefore, early excision and grafting are usually never resorted to, reliance being placed on pressure dressings and grafting only after healthy granulations have made their appearance. Even at the time of grafting extreme gentleness is in order lest secondary hemorrhage occur.[19]

The following is a case of frostbite handled by the method described previously:

CASE IV. M. B., a twenty-seven year old white male, was admitted on March 2, 1950, to the Redford branch of the Detroit Receiving Hospital with a history of suffering severe frostbite of both hands while passing out handbills. He gave a history of suffering a similar injury several years before. Both hands were markedly erythrematous and warm with cyanosis of the fingertips. There were bulae on several fingers, especially the right hand. (Fig. 6A and B.) The fingers were gently cleansed, a bilateral cervical sympathetic block was performed and pressure dressings employing nupercaine ointment were applied. (Fig. 6C.) He was placed on heparin, mg. 50, every four hours for one week. At the end of that time the blisters were débrided (Fig. 6D) and vaseline gauze pressure dressings were applied.

At the end of three and one-half weeks the nails and superficial skin had sloughed, leaving healthy nails and skin underneath. (Fig. 6E and F.)

The following case presents the problems encountered when early skin grafting with adequate care is neglected:

CASE V. G. M., a thirty-seven year old colored female, suffered severe burns of the left side of the face, left axilla, left arm and both hands when she fell into an open fireplace in 1937. She was treated at home and developed severe contractures. (Fig. 7A.) There was a severe flexion contracture of the right hand and wrist involving all of the fingers and a severe extension contracture of the left wrist. In addition there was a flexion contracture of the left elbow and rather severe disfigurement of the left side of the face. This case report deals with the correction of the contracture of the left wrist. (Fig. 7B.)

She was admitted to the City of Detroit Receiving Hospital on May 3, 1948, and the scar tissue on the back of the left hand was excised (Fig. 7C) and a muff type of graft applied by inserting the hand under the abdominal skin. (Fig. 7D.) On May 12, 1948, under 1 per cent procaine hydrochloride anesthesia the lower portion of the flap was freed. On May 26, 1948, the more proximal portion was freed. (Fig. 7E.) The flap was sutured in place and the hand was dressed on a metal splint. The donor site on the abdomen was closed by means of a split-thickness graft. Two years later she had a good functioning left hand. (Fig. 7F and G.)

SUMMARY

The essential factors in the treatment of burns of the hand are avoidance of additional injury to that already taken place, by protection against added chemical, bacterial or mechanical insult; removal of contaminating microorganisms and then mechanical removal of obviously non-viable tissues; careful application of occlusive pressure dressing; the use of a universal splint in order to prevent deforming contractures and to maintain grafts in position; the conversion of an open wound into a closed wound as soon as possible and perseverance in restoration of maximal function.

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DISCUSSION OF PAPERS BY DRS. MASON, SILER GRAHAM, ALLEN AND MILLER AND POSCH

Sterling Bunnell (San Francisco, Calif.): In the first place, I want to express my admiration and appreciation, as I know all of you do, for this very interesting and enlightening series of papers, all based on direct experience.

I might emphasize that the fate of the injured hand depends largely on the first dressing or the first treatment. That shows the importance of the subject. The first treatment, as Dr. Mason pointed out, must close over all open wounds, line up the skeleton and prevent infection. Of course, the most careful dèbridement and atraumatic technic is necessary because trauma leads to infection.

The alignment of the skeleton is exceedingly important in early treatment. Once that is done, a good deal of trouble is saved. The position of each joint is extremely important, from the early treatment on—and also the preservation movement.

We find in crippled hands, when they come for secondary repair, a lot of cicatrix that might have been avoided by preventing the infection. We find joints ankylosed from sepsis and osteomyelitis with sequestrae that would have been avoided by preventing infection. The position of the hand will be like that of a claw, with the wrist flexed, proximal finger joints extended or hyperextended, thumb at the side and fingers clawed. All of the joints of the hand will be stiff. That could all have been prevented.

The matter of infection has been covered meticulously. The hand wound should be covered over soon. It was mentioned that we should swing grafts from the vicinity, whenever possible, use split skin grafts and even cover the hand by skin pedicle from the abdomen immediately following the injury and thus save weeks and months of trouble and final disability.

Before penicillin and the antibiotics it was not safe to attach an open wound to the abdomen. The abdominal fat was too vulnerable. I can think back to cases in which we tried it and got infection because it would not stand the dirt of a street wound. But now with penicillin and débridement we can get by with that procedure, as the wounds heal quickly and the joints of the hand remain limber. An open wound will stiffen up the whole hand, because an open hand means swelling and immobility, and a long time of absorption from products of infection. Swelling and immobility cause stiffening.

The claw position of the hand can be prevented by tending to the key joints. There are two such key joints: one is the wrist joint and the other the proximal joint of each finger. When our hands are in the position of function, the muscle balance places our digits in the position of function and holds them so. When we flex the wrist, the extensors becomes tight and draw the hand into the claw position. Dorsiflex the wrist and the hand comes back into the position of function. The wrist, being the key joint, should be kept in dorsiflexion.

Similarly, if we allow the proximal finger joints to heal in straight or hyperextended position, they will stiffen so and cannot be flexed because the collateral ligaments will have shrunken. Also, if those joints are straight, the other finger joints from muscle balance will be clawed. If we always keep the proximal finger joints flexed, the other finger joints will be only semiflexed. In that way, we can avoid a great deal of trouble.

To avoid the stiffness I mentioned, we should avoid infection. Another cause for that stiffness is splinting the hands too long or splinting in a poor position. Many a splint or plaster cast has been applied to an injured hand in such a way that it wrecks the hand. To put the wrist straight or in flexion after an injury is bad. To put the proximal finger joints straight is also bad. Often, a cast is prolonged down the hand past the distal crease in the palm and over the fingers, and that wrecks the fingers.

Another thing that wrecks the fingers is to use a banjo splint in which the fingers are all pulled out straight by separate wires to this banjo. That will stiffen a hand more than anything else. Any setting of fractures should always be in the position of function.

If we do not allow early movement, the joints will stiffen and we will never get them moving again. It is much easier to prevent stiffening than to cure it once it is established. Later, one will have to start in with the key joints and get them into the position of function and then start movement as in occupational therapy. You cannot start that to advantage until you get the hand aligned in the position of function. As soon as possible, we should start injured hands moving and keep them moving.

Burned hands always stiffen so, as soon as possible, they should be started moving. Crushed hands particularly should have movement early. Movement should be continued up to the time of returning to work.

I want to say a word about nerves. I think nerves are much more important than is generally considered. All these little nerves in the hand should be repaired and primarily, if possible, because a hand is a sense organ. It has two functions: sensation and prehension. All those nerves in the hand can be repaired. Also, the nerves all the way up the arm, the brachial plexus and the arm nerves, should be repaired early because if they are not, the hand is wrecked. Those nerves are hand nerves. Brachial plexus injuries mean wrecked hands. Nerves of the arm should take priority over bones or joints. Over and over again, you will see an injury of the humerus or of the elbow. The nerves are severed but they have not been joined until the humerus becomes united or the elbow is tended to. That may take two years. Then there is no use joining the nerves for motor function, because by that time the charges are irreversible. The lower portion of the nerve has undergone fibrosis and the muscles are atrophied. They will never have function again. Therefore, nerves should take priority over bones and joints. Once an elbow is stiffened, you can never get the nerves together, because you have to flex an elbow to get nerve ends together, the same as leg nerves, where you must flex the knee.

As to the primary suture of nerves, I think the sooner they are sutured, the better. Some think, however, that they should not be sutured early and it is better to wait for twenty-one days. I do not think that is correct. It is based on the fact that you cannot tell how far the nerves are injured. Microscopically, you can, but if it is a contused wound or a gunshot wound, just cut them back a little further.

The best results I have seen were where the nerves have been sutured at once. In many wounds you cannot suture them at once because it is a crushed wound or a dirty wound. Then one can use one stainless steel wire stitch just to hold the ends in approximation so they will not retract. That is sufficient. Infection may occur but the nerve end will stay in approximation, and an accurate neurorrhaphy can be done later.

Suppose a nerve has been sutured primarily in the usual way. It is probably not a good juncture and the degree of regeneration is directly in proportion to the accuracy of the juncture. If the nerve has been sutured primarily by other than an expert, it is best to resuture it so as to obtain an accurate juncture. Almost always one finds a very rough juncture when it has been sutured primarily by people who are not accustomed to suturing nerves. If the surgeon is adept at this procedure and after thorough débridement sutures the nerve accurately, a good result can be gained by primary suture.

Frederick A. Jostes (St. Louis, Mo.): This organization, I think, has a rare opportunity to teach the utter importance of proper initial treatment in trauma of the hand. We all know that it is usually the general practitioner who sees these hands first. We should do our best to help him. We all know that mismanagement may lead to greater destruction of tissue and loss of tissue and to much more surgery than would have been necessary if proper initial treatment had been instituted. Therefore, it strikes me that every effort should be made on the part of the members of this organization to spread the gospel wherever possible.

To my mind, there is no more dramatic surgery than surgery of the hand, and none more tedious but also none more gratifying when a good result

is obtained. I should like to say that we should not be satisfied with mediocre results.

MARTIN C. LINDEM (Salt Lake City, Utah): I think it is good to have this nucleus from Chicago and their associates from elsewhere over the country come out and review the principles of treatment of wounds again. The subject, it seems to me, in many of the medical schools is very much neglected these days. The student is taught procedures and definitive surgery to such a degree that he forgets that the patient should be treated from the beginning on surgical principles of treatment of wounds and from the time when he was injured.

I would like to call attention to the probable omission of care from the time when the injury took place until the surgeon who is doing the definitive surgery has been reached. One of the most important things is to get a hand in the proper splint and dressing at once after injury. Most of the hands we see brought in for definitive surgery are dressed with a little loose dressing, with blood pouring all over, splinting and preventives for infection omitted. A nice, soft splint, under lots of padding, which should be sterile, a pressure dressing, and complete immobilization of the extremity as far up as possible will make it much easier for the surgeon who sees the case later to carry on definitive care.

PAUL W. VESTAL (New Haven, Conn.): The one thing that disturbed me about the program was that there might be some difference of opinion, as we have in our area in New England, or rather in certain areas, about suturing tendons and nerves early. We find that here in this society there is common agreement on fundamental principles. But we still have to go back home and preach the gospel a little bit, particularly to the family physician.

There is one point I might make, that in industrial wounds, I have found suture can be done immediately, and "immediately" means three to six hours, without fear of infection. Cutting oils and other dirty matter in industry look rather foul, but in culturing all of them, we have never found any organisms. Therefore, I would like to say that you can feel free to suture those wounds at once.

DONALD M. GLOVER (Cleveland, O.): I should like to ask questions of two or three of the contributors, if I may. First, to Dr. Graham, concerning the advisability of doing tendon grafts in fingers in which all soft tissue has been destroyed and in which it is necessary to replace the palmar skin by means of some sort of a flap; and, also, whether or not he ever feels justified in leaving a finger if it is impractical to do a graft, especially a middle or ring finger, if the other one is unimpaired. In a few instances which I have seen the patient found that with a functioning middle or ring finger, the movement carrying the other finger with it was fairly satisfactory and was preferred to amputation.

I was very glad to hear Dr. Allen's insistence upon early definitive treatment of crushing wounds of the hand, and I think that is worthy of emphasis, particularly in those with primarily subcutaneous injury; because these, if left to subside, certainly provide very badly disabled hands.

I should like to ask him, or Dr. Miller or Dr. Posch, what their experience has been with immediate grafts of deep burns of the hands, that is, with the primary dressing, which at least theoretically might be considered ideal in some cases.

I should also like to ask any of the essayists what can be done with the ankylosed fingers resulting from severe burns, the hand which is left with damaged joints resulting from the burn around the joint capsules which seem to be irreparable. I have had very poor success with any type of arthoplasty on interphalangeal joints, although the metacarpal phalangeal joints sometimes are satisfactorily repaired in this manner. Still, one does not wish to sacrifice such fingers because they are very valuable and often the stunted, contracted fingers may be all the patient has with which to go through life.

COL. EDWIN J. PULASKI (Fort Sam Houston, Tex.): With regard to the problem of infection in the open wound, about ten years ago we made an intensive study of the bacteriology of the fresh traumatic wound, which was repeated in the 1942–1944 National Research Council program for the study of wounds and burns. Both studies revealed that approximately 75 per cent of wounds which were seen at the hospital within the first hour had staphylococci present. Of that 75 per cent, fewer than 20 per cent were of the invasive pathogenic type. That is, only one wound out of every six had pathogenic organisms present and these were present in very small numbers.

The hemolytic streptococcus, which is perhaps the most invasive of the common organisms in open wounds, was isolated much less frequently.

In a large series of cases which have been collected in England by the Medical Research Council, the incidence of infection in hand wounds treated as described this afternoon was under 2 per cent. The question arises, therefore, are we or are we not justified in giving antibiotic coverage to all patients with open wounds in the face of an incidence of 2 per cent infection when the wound is properly treated. It is open to question whether routine antibiotics do significantly reduce or eliminate infection below 2 per cent.

Our management of this problem is as follows: In the incised lacerated wound seen early we give no antibiotic prophylaxis. In the contused, lacerated

wound we give 300,000 units of penicillin G once only. We consider that the most important element in prophylaxis against infection is exercise of good surgical technic as has been emphasized this afternoon. The employment of antibiotics as local antiseptics is not practiced or recommended.

We now see very infrequently hemolytic streptococcic wound infections. Local staphylococcic infection now predominates. By and large they are the sequel of residual devitalized tissue, blood clot, or serum collected in dead space and it is very questionable just how much antibiotics may be expected to be effective over and above good surgical treatment.

HARRY E. MOCK, JR. (Chicago, Ill.): I want to direct my discussion to Dr. Allen's subject, "crushing wounds of the hand."

I wish to re-emphasize one method of obtaining skin covering in crushing injuries with avulsion of the skin, that of removing the loose skin, defatting it and then reapplying it as a full-thickness graft. The subject has been discussed before this group on previous occasions, but I believe it is worthy of mention again.

We had a patient* whose arm had gone through a printing press up to the junction of the middle and upper thirds. There was a circular laceration at the upper border of the injured area with a pedicle approximately ½ inch in width on the dorsum. There was a similar circular laceration at the wrist with a narrow pedicle of intact skin on the dorsum. There was a long laceration on the volar surface connecting these two circular lacerations. The entire skin flap was torn loose from the subcutaneous tissues. There was a longitudinal laceration of the palm extending out onto the volar surface of the proximal phalanx of the middle finger up to the flexion crease of the proximal interphalangeal joint. The volar carpal ligament was shredded, the carpus completely disrupted and the hand was lying on the dorsum of the forearm.

The patient's initial treatment was directed toward combating shock. Three hours after injury he was given a general anesthetic and the skin carefully cleansed with soap and water. The two small pedicles of the large loose flap were then cut and the skin removed. The skin was tacked to a sterile board and completely defatted. The wound was débrided and all non-viable tissue excised. The wrist bones were fitted together as well as possible, the dislocation reduced and position maintained by repairing the volar carpal ligament. The laceration of the palm and middle finger was then repaired. All of the fat that remained adherent to the fascia of the forearm was then excised and the defatted skin put back and sutured in place. Pressure dressings and plaster splint were applied. The arm was kept elevated.

The full-thickness skin graft took well. There was only one small skin infarct on the dorsum of the forearm. This was superficial and epithelized without special treatment. The skin had a much more normal appearance than would split-thickness grafts.

We all know that merely replacing loosened skin in avulsion injuries almost invariably leads to later development of ischemic necrosis and slough. Removing this skin completely and defatting it as well as the bed upon which it is to lie, converts it into a full-thickness skin graft that is exactly the right size and shape. It gives a more normal skin covering and at the end of a year it is hard to tell it from the normal surrounding skin. Of course, there are instances in which the skin is so badly traumatized that this method is not feasible, but in actual practice these instances are few and far between. In my opinion this method is so worth while that I believe it deserves the serious consideration of all who treat this type of injury.

* Dr. Mock showed slides of the patient's arm six weeks after injury.

SEQUELAE OF VASCULAR INJURIES

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THE study of trauma and its treatment is becoming increasingly more important. Some other types of surgery may possibly become obsolete as medical knowledge advances but the surgery of trauma is here to stay.

Trauma to blood vessels is simply an important subdivision of the main subject. As the arteries are of more significance than the veins most of this presentation will have to do with the former. We have taken the liberty of confining the discussion to the sequelae of vascular injuries in the extremities.

It is rather difficult for a single individual to gain a large experience in blood vessel injuries in civilian practice. This paper is based on the work of others and on experience in the laboratory during the last war and in everyday practice. It includes discussion of failures and successes and will, it is hoped, be of some practical use to physicians as they encounter problems of vascular trauma in their own practices.

Before dealing with the specific sequelae of vascular injuries we should like to list four general principles which we have found useful when confronted with arterial insufficiency in an extremity: (1) Do not delay; (2) do not elevate; (3) do not heat and (4) do not refrigerate.

The sequelae of vascular injuries of the extremities are diagrammatically illustrated in Figure 1 which has been borrowed from Sir James Learmonth[4] with one or two modifications.

COMPLETE SEVERANCE

This may result from a stab wound, a bullet, a piece of glass or sharp metal or the surgeon's knife. If the artery is a large one, the picture may be dramatic. There may be spurting bright red blood or a steadily expanding limb with the patient showing the signs of loss of blood. Supportive measures and exploration are indicated.

In the case of smaller arteries ligation may be resorted to readily. In our opinion any artery in the upper extremity may be ligated with more or less impunity. Fine braided silk is the ligature material of choice and transfixion of the vessel is in order to prevent the possibility

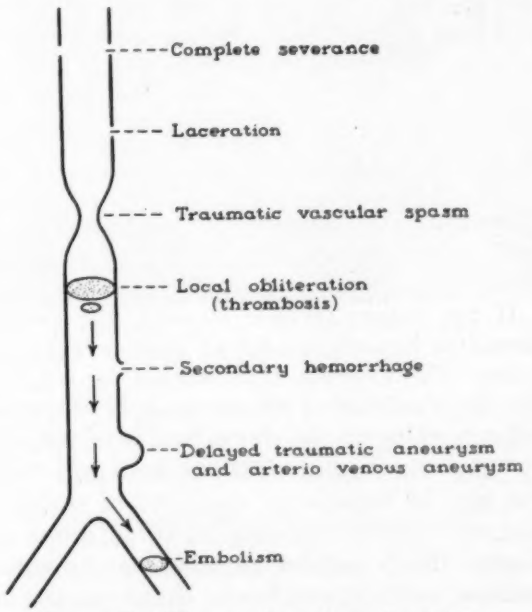

FIG. 1. Possible sequelae of vascular injury.

of slipping of the ligature. It is well to ligate the distal as well as the proximal cut end since reflux bleeding occurs from the distal end by way of the collateral circulation.

When a large artery such as the femoral above the profunda or the popliteal is completely severed, it is well to consider some method of restoring continuity. Retraction of the cut ends is usually so great as to preclude bringing them together for direct suture. The gap may be bridged by utilizing a vein graft. A section of the companion vein, great saphenous or external jugular vein may be used. The vein graft must be reversed when it is placed in the arterial system so that valves if present will not impede the flow of blood. The vein may be sewn in place by the triangulation

technic which is based on Frouin's method of end-to-end vascular suture as described by Guthrie in 1912. (Fig. 2.) The suture material is No. ooooo silk on an atraumatic needle. The vein graft may be attached to the artery by means of Blakemore-Lord vitallium® cuffs.[1]

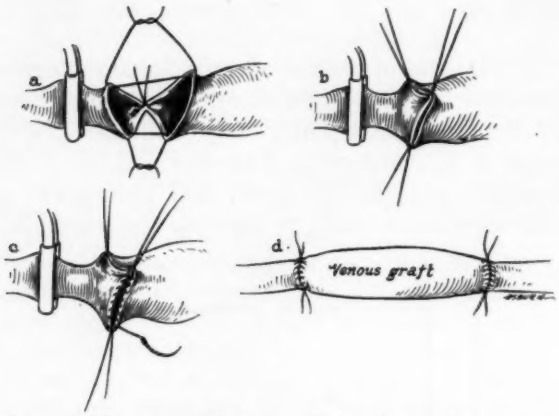

FIG. 2. The triangulation technic of vascular suture.

Experience in either of these technics is best gained on the dog in the experimental laboratory.

If the suture technic is used, the patient should be heparinized for at least seventy-two hours. The clotting time should be kept in the neighborhood of fifteen minutes. This is a difficult thing to do. It is best accomplished by the continuous intravenous drip with 200 mg. of heparin in 1,000 cc. of saline or dextrose solution allowing 24 to 30 drops per minute. Each patient presents an individual problem and the number of drops per minute is regulated according to the clotting time. We are now experimenting with a pump which delivers a known quantity of fluid in a definite period. We hope by this method to eliminate the trouble we have had in maintaining a definite number of drops per minute.

Occasionally, one may ligate a major vessel such as the popliteal artery and not lose the extremity. This was done in the case of a wound in the popliteal space of an air gunner whose popliteal artery was severed by a piece of "flak." The artery was ligated and the leg remained viable. The patient however presented the neurologic disturbances illustrated in Figure 3.

When it is found necessary to ligate a major artery such as the popliteal, we believe it is wise to do a concomitant lumbar sympathectomy to insure maximal collateral flow.

FIG. 3. Disturbances of sensation following ligation of the right popliteal artery. Loss of sensation to pin prick is represented by cross hatching, while loss of sensation to cotton wool is represented by stippling. In this case, in approximately the posterior two-thirds of the plantar surface of the foot, represented by the lighter stippling and cross hatching, there was slight hypo-algesia. Some areas at this site gave rise to a burning sensation when subjected to pin prick.

LACERATION OF AN ARTERY

This usually results from injury by a knife, a piece of glass or sharp metal. If the condition is recognized early and repair of the laceration is effected, the development of a false aneurysm is prevented. If the history is that of spurting bright red blood or an expanding limb following a penetrating injury, it is best to explore.

A false aneurysm of an ulnar artery has been observed which could have been prevented by exploration and ligation of the artery at the time of injury. A workman injured his forearm with a drill. Bleeding was stopped by pressure and the skin wound sutured. A pulsatile swelling and signs of involvement of the ulnar nerve later developed. When the laceration involves a major artery, it is often possible to close the rent by vascular suture. Here again it is best to heparinize the patient for seventy-two hours if such a procedure can be adequately and safely carried out.

TRAUMATIC VASCULAR SPASM

This may result from the impact of some object against the artery or from stretching the artery. An example of the former would be that of a fragment of bone; an example of the latter would be stretching the artery with a distracting apparatus in "setting" a fracture.

FIG. 4. Large foreign body which caused spasm of the lower part of the femoral and the popliteal artery.

Both of these causes have been observed by the authors.

If the signs of spasm, that is, a cold, pulseless, pale or mottled limb, persist after the injection of papaverine, the administration of alcohol by mouth or intravenously, warming the trunk and procaine injection of the appropriate sympathetic ganglia, one must be prepared to explore and consider arterectomy. As a matter of fact when exploration is carried out one may find something upon which the above mentioned conservative measures could have no effect. Figure 4 shows a foreign body which caused spasm of the lower part of the femoral and the popliteal artery.

Recently several authors including Carter, Richards and Zachary and Tillotson and Coventry have drawn attention to the anterior tibial syndrome. This is a syndrome occurring in fit young men and consists of ischemic necrosis of the anterior tibial compartment of the leg with a lesion of the anterior tibial nerve. From a pathogenic standpoint the sequence of events is given as follows: unaccustomed exertion, muscle trauma, increased pressure within the anterior compartment, impaired blood supply to the affected muscles and ischemic necrosis. Arterial compression is considered to be the important etiologic factor. Although arterial spasm is not considered to be the important factor in the muscle necrosis, it is convenient to mention the syndrome here. If the syndrome is recognized early, *rest* alone may prevent irreversible damage to the muscles; but if paralysis has developed, surgical decompression of the anterior tibial compartment as an emergency procedure is advocated.

FIG. 5. Popliteal artery (opened) which had been damaged by a high tibial fracture.

LOCAL OBLITERATION (THROMBOSIS)

As mentioned previously, on exploration of an injured artery one may find that one is not simply dealing with spasm. The artery may have been so disturbed that the intima has been seriously damaged, with resultant thrombosis. This happened in one of our cases. Birdshot contused the brachial artery but had not perforated it. Resection of the thrombosed section of artery was carried out. In the case of the femoral artery above the profunda or popliteal artery one may have to consider a vein graft in addition to arterectomy.

Local obliteration of the brachial artery has been observed in a case of supracondylar fracture of the humerus in a child. Exploration revealed that no amount of closed manipulation would have restored the radial pulse. Local resection of the damaged segment of artery and a vein graft, the later now believed unnecessary in the brachial artery, resulted in

FIG. 6. Arteriovenous fistula with direct communication.

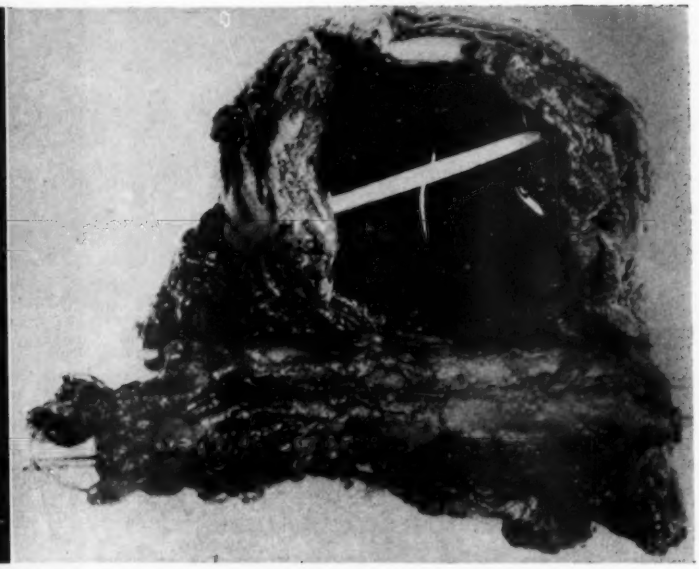

FIG. 7. Arteriovenous fistula with associated sac.

restoration of the blood supply. Volkmann's ischemic contracture did not develop.

Figure 5 shows a popliteal artery which was damaged by a high tibial fracture; the lumen of the artery was obliterated by a thrombus. The patient was seen late, gangrene was present and amputation above the knee was necessary.

In another case a gangrenous foot was seen three weeks after a dislocated knee had been reduced. The intima of the popliteal artery had been so damaged at the time of dislocation that local obliteration due to thrombosis occurred. It is well to be on the lookout for arterial insufficiency following the reduction of a dislocated knee. In fact it is well to take the necessary steps to forestall such a complication.

SECONDARY HEMORRHAGE

This usually occurs as the result of sepsis in a wound. It is an impression that since the advent of chemotherapy and the use of antibiotics the incidence of secondary hemorrhage has been reduced. Hemorrhage from the slipping of a ligature may usually be prevented by transfixing the vessel with a silk ligature.

When bleeding occurs and packing is not effective, the usual advice is to open the wound, identify the bleeding point, clamp it and tie it. In the presence of a necrotic mass in an infected wound this may not be easily done. In the extremities one may have to resort to ligature of the artery proximal to the wound. It is recognized that this is a procedure which is not generally advocated. When an artery is ligated, it is well not to do it in continuity—the artery is severed between ligatures. Amputation is the last resort in controlling secondary hemorrhage.

DELAYED TRAUMATIC ANEURYSM

Laceration of an artery which is not repaired may result in a traumatic aneurysm. A gunshot or stab wound, an automobile or airplane accident or some flying glass may cause such a laceration. The clinical features of an aneurysm may be summarized as follows: (1) Globular pulsating swelling; (2) distinct thrill and systolic murmur; (3) congestion and edema of the parts beyond; (4) pain and disturbances of sensation and (5) erosion phenomena.

Arterial aneurysms are more difficult to deal with than are arteriovenous aneurysms or fistulas because the collateral circulation does not develop as well in the former as in the latter. Ligation of a major artery and extirpation of the aneurysm may be dangerous. In suitable cases the continuity of the artery may be restored by a vein graft such as advocated by Murray. The vein graft may be fixed in place by means of Blakemore-Lord cuffs. A strip of fascia may be placed around the graft in an effort to prevent too much

distention of the graft. If the continuity is not restored, all the means at one's disposal should be used to improve the collateral circulation.

ARTERIOVENOUS ANEURYSM OR FISTULA

Only the acquired type is considered in this presentation. Acquired arteriovenous fistulas seen in the past most often were caused by gunshot or stab wounds. With the increased incidence of serious automobile and airplane accidents, cases of arteriovenous fistula now arise from such accidents.[6] The local signs of such a condition are as follows: (1) Pulsating lump; (2) dilatation of veins and (3) characteristic thrill and murmur. It is not proposed to deal with the systemic effects.

Acquired arteriovenous fistulas are of two main types. Figure 6 illustrates the type in which the communication is direct between the artery and the vein. Figure 7 illustrates the type in which there is an associated sac.

Collateral circulation develops well in arteriovenous fistulas. One is usually cautioned to wait three to six months before operating to insure the development of maximal collateral circulation. One of us (J. M. J.) has operated as early as two weeks without any ill effects. There is a danger of waiting too long. In one of our cases a lesion was seen three years after injury. In this case the condition was complicated by a false aneurysm superimposed on an arteriovenous fistula and required two operative procedures for correction. The anatomic relations were so disturbed and the tissues so altered that we were unable to deal with the situation at one sitting. This is not the only instance in which a false aneurysm has developed in a case of arteriovenous fistula due to rupture of the original sac or communication between the artery and vein.

The most practical way of dealing with an arteriovenous fistula is quadruple ligation and excision. Occasionally when the communication is a direct one, the aperture in the artery may be repaired by a transvenous approach. The artery is repaired as one would repair an arterial laceration and the vein is sacrificed. *Arteriography* is often useful in these cases to locate the site of the communication. Figure 8 illustrates this point. Note the site at which the venae comites suddenly become filled with the media; this indicates the site of the communication. An arteriogram often gives valuable information regarding the collateral circulation.

FIG. 8. Arteriogram showing the site of arteriovenous communication.

EMBOLISM

Occasionally a clot may become dislodged from a thrombosed artery and produce signs of arterial insufficiency at a lower level. This will not occur if the original site of thrombosis has been adequately dealt with. When it does occur and is recent, embolectomy may be done. This is another instance which calls for controlled heparinization. If the embolus is old and the intima damaged at its site of lodgment, arterectomy may be done.

FIG. 9. Components of the modified Robert Jones protective dressing are shown from left to right, absorbent cotton, ace bandages, eider down and sheet wadding.

Before closing, mention should be made of a useful type of dressing for limbs which have been operated upon for vascular injuries. It is a modification of the Sir Robert Jones pressure dressing. Its use here is not to apply pressure but to afford protection of the relatively ischemic limb. The components of the dressing are illustrated in Figure 9 and consist of sterile sheet wadding, absorbent cotton, eider down and ace bandages. The latter are loosely applied. Such a dressing keeps the knee straight and offers protection by its bulk.

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TRAUMATIC ARTERIOVENOUS FISTULA

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A workman struck a bolt with a sledge hammer. A small piece of steel chipped off and flew into the workman's upper left anterior thigh. The wound bled profusely and a pressure dressing was applied.

Physical examination upon entrance to the hospital revealed a young well developed, well nourished adult male. There was a 7 mm. puncture wound on the anterior medial surface of the upper third of the left thigh. X-rays revealed a small deeply embedded foreign body. The blood pressure was 88/60; two hours later it was 112/76 and remained within normal limits until discharge from the hospital six days later. The temperature rose to 99°F. on three occasions during his hospital stay. The laboratory work upon admission was within normal limits. Urinalysis showed no abnormalities. Three hundred thousand units of penicillin procaine in oil were given on admission and repeated five days later.

The patient returned to work eight days after his injury and complained of pain in the upper left anterior thigh. X-rays were repeated and it was found that the foreign body had not moved. The puncture wound was well healed and the hematoma was almost completely absorbed. Some localized swelling and tenderness did remain. This was the first time a machinery bruit was heard and a thrill was palpated over the injured area. His temperature was 101°F. and his pulse was 120. He was again hospitalized for eight days and received procaine penicillin intramuscularly and heat locally to the injured area.

This workman was seen at frequent intervals. Four weeks after injury he was re-examined and his chief complaints were that he tired easily and had pain in his left thigh.

The circulatory examination revealed the following: dorsalis pedis artery (by palpation) 4 plus on the right and left; posterior tibial artery (by palpation) 4 plus on the right and 2 plus on the left; skin temperature of both feet was the same (by palpation); by pressure, capillary return was 2 seconds in each toe; the elevation to dependence test was 10 seconds on the right and 8 seconds on the left; venous filling after dependence was 30 seconds on the right and 35 seconds on the left; blood pressure in the arms was 140/70 on the right and 134/70 on the left; blood pressure with the femoral artery closed was 120/70; pulse at the wrist was 104 and with the femoral artery closed was 84.

The heart was within normal limits and a machinery bruit was heard over the upper left thigh. There was a palpable thrill over the same area.

There was a consultation three months after injury and the report expressed that there was a typical arteriovenous fistula with a machinery bruit. The left thigh was found to be 4 cm. larger in circumference than the normal right at the midthigh. The collateral circulation was reported to be adequate and the patient in good physical condition for operation at any time.

In general, the high pressure blood from the artery into the vein results in localized dilatation of the vein and later the valves become incompetent. In this case some superficial veins in the leg became noticeably larger. The increased flow of blood through the proximal artery sometimes dilates it. Surface temperatures in the vicinity of the fistula are increased. Distal to the fistula surface, temperatures usually decrease because of defective blood supply.

It is known from extensive experience that after the fistula is closed there is a tendency for all functional changes to return to normal. There is a decrease in the pulse rate and a rise of the diastolic and mean arterial pressures. There was no spontaneous recovery in this case as the initial pressure over the injury did not obliterate the fistula. Operation may be carried out immediately and the artery and vein repaired if this is possible; but if early operation and repair are not possible, sufficient collaterals have not been developed. Operation may be delayed and in most cases is beneficial.

Therefore, fourteen weeks after the injury the workman was admitted to the hospital for operative intervention. Under spinal anesthesia a left lumbar sympathectomy was performed through a 7 inch transverse incision extending from the lateral border of the rectus to the costal margin. The second, third and fourth lumbar sympathetic chain containing three large ganglia were excised. The recovery from this operation was uneventful and prompt with a definitely warmer left lower extremity.

Fifteen weeks after injury and one week after sympathectomy he was prepared for exploration

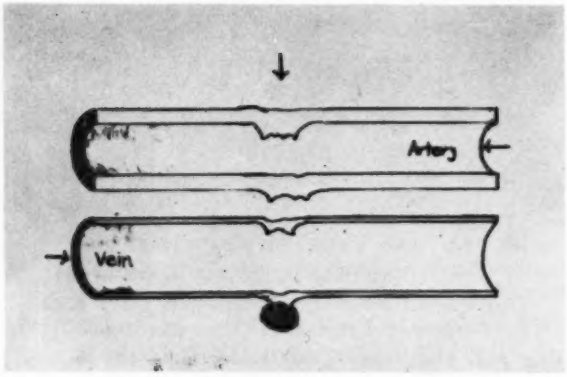

FIG. 1. Diagram showing passage of foreign body through both the artery and vein.

of the arteriovenous fistula. Under gas-oxygen anesthesia a 22 cm. incision was made on the anterior left thigh over the course of the femoral artery. The proximal femoral artery and vein were isolated and tapes passed beneath them distal to the inguinal ligament. A similar procedure was carried out distal to the fistula. The dissection was carefully carried closer to the fistula. At the site of the fistula the vein was directly beneath the artery with a bulging, pulsating mass between the artery and vein. Proximal and distal artery and vein were shut off by means of the tapes and prompt dissection of the fistulous area was carried out. The foreign body had passed completely through the anterior and posterior walls of both artery and vein and had become attached to the undersurface of the vein. (Fig. 1.)

Upon inspection and careful planning it was impossible to repair the anterior and posterior surfaces of both artery and vein without materially narrowing these structures. It was therefore decided to do a quadruple ligation and resection of 2 inches of the fistulous portion of the artery and vein. This procedure was carried out. (Fig. 2.)

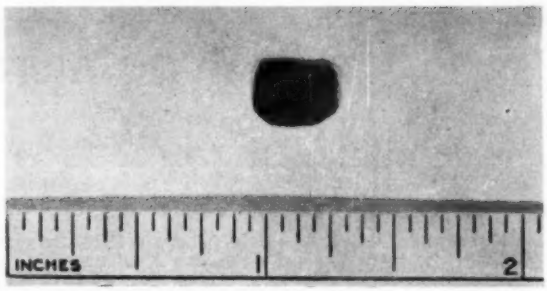

FIG. 2. Foreign body.

Postoperatively the leg and foot were quite pink and warm, and the dorsalis pedis artery could be palpated. The postoperative course was satisfactory except for pain in the calf of the right leg on the third day for which heparin therapy was carried out. Temperature—to 101°F. Pulse—70–96.

The blood work-up postoperatively was within normal limits. An electrocardiogram was also considered normal and x-rays of the chest showed no gross pulmonary disease and a normal cardiothoracic ratio.

SUMMARY

A case history is presented in which a foreign body of steel entered the upper anterior thigh of a workman. The clinical course was typical of an arteriovenous fistula. Operations were carried out first for a lumbar sympathectomy fourteen weeks after injury, and a quadruple ligation and resection fifteen weeks after injury. Exploratory operation revealed that the anterior and posterior surfaces of both artery and vein had been completely lacerated by the foreign body. A practically uneventful typical course was followed in this case.

LACERATION OF THE INFERIOR VENA CAVA WITH DELAYED HEMORRHAGE AND PRIMARY SUTURE*

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THE opportunity to repair traumatic lacerations of the major vessels of the abdomen or chest rarely presents itself. Accidental lacerations of the inferior vena cava occurring during surgery can occasionally be repaired.[1–4] But in cases of external trauma the patient usually exsanguinates before exploration can be carried out. In a patient recently treated in the Cleveland City Hospital, however, hemorrhage from a laceration of the inferior vena cava was effectively contained within the retroperitoneal space and concealed until surgical exploration was in progress, thus allowing primary suture of the vessel with complete recovery.

CASE REPORT

E. S., a twenty-five year old colored male, was shot in the left flank about 1 A.M. on August 25, 1949. He was taken to a local hospital, given plasma and stimulants and transferred to Cleveland City Hospital at 3 A.M.

Examination revealed an acutely ill patient who, however, walked without help to the bathroom when left unattended for a moment. The pulse was 140, respirations 20 and blood pressure 120/80. There was a penetrating wound of the left flank with a point of entrance approximately 10 cm. to the left of the twelfth thoracic spine. A bullet could be felt in the subcutaneous tissues over the ninth rib in the right anterior axillary line. Breath sounds were diminished over the right lower lung fields. The abdomen was diffusely tender and rigid and presented no sounds. The red cell count was 4.45 million and there were 12 gm. of hemoglobin. The urine contained 2 plus albumin and 10 to 12 red blood cells per high power field.

The patient was given plasma and whole blood and taken to surgery about five and one-half hours after injury. Gas-oxygen-ether were administered and exploration through a transverse upper abdominal incision was carried out. A large quantity of blood was found in the peritoneal cavity and lacerations of the anterior surface of the second part of the duodenum and liver noted. Extensive hemorrhage was seen in the retroperitoneal space surrounding the duodenum. The anterior perforation of the duodenum was closed and the duodenum mobilized by incising the lateral peritoneal reflection. This maneuver resulted in massive hemorrhage from the region of the inferior vena cava. Investigation revealed the source of this bleeding to be a hole in the inferior vena cava about 2½ cm. in diameter. At this point the patient went into profound shock; no blood pressure or pulse could be obtained. A second intravenous infusion was started in the other arm and a large cannula was placed in the ankle vein for the administration of additional blood and plasma. The vena cava was then temporarily occluded above and below the laceration by pressure and the defect repaired with interrupted arterial silk sutures. This closure proved effective after the pressure was released. A posterior laceration of the duodenum was then found and also closed. Oxycel was placed over the wound in the vena cava and over the lacerations of the liver. Penrose drains were placed down to the duodenum and the abdomen closed by means of through-and-through interrupted silk sutures.

During operation and within the first six hours postoperatively 2,000 cc. of whole blood and 3,000 c.c of plasma were given. The patient's blood pressure slowly returned to normal within six hours; during the first twenty-four hours the urinary output was 1,400 cc. On the second postoperative day the patient developed fluid in the right chest and this required daily aspiration but it resolved without residua by the tenth day. Venograms of the vena cava made on September 12, 1949, failed to show any evidence of thrombosis. (Fig. 1.)

On September 24th the patient was discharged sympatomatic. Examination after three months failed to reveal any abnormalities except some weakness of the abdominal wall. (Fig. 2.)

COMMENT

Methods for the control of hemorrhage from the vena cava as listed by Walters and Priestly include: packing, partial or lateral ligation, complete ligation at one or more levels, application of clamps which are left in place and suture of the tear.[4]

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FIG. 1. Venogram (retouched) made postoperatively showing slight defect at point of suture.

In this case the high level of injury made ligation and packing dangerous because of the probability of thrombosis with extension to the renal veins and consequent uremia. The apparent loss of tissue from the wall of the vessel made the application of clamps and lateral ligation technically impossible. Primary suture proved effective.

That thrombosis had been avoided was confirmed by the absence of edema postoperatively and the normal venograms. This was due in part to the vigorous attack on stasis with massive replacement therapy and the liberal use of penicillin and streptomycin.

Similar cases have been reported previously. Kidd was able to gather ten cases in the literature of injury to the inferior vena cava secondary to external trauma and he added another case.[5] Suturing has been employed eight times and there were two deaths in this group.

FIG. 2. Photograph made three months postoperatively revealing some weakness of abdominal wound.

Fraser recently reported a case requiring ligation.[6]

SUMMARY

1. A case of traumatic laceration of the inferior vena cava above the renal vein is reported wherein suture six hours after injury proved effective.

2. Methods for the control of hemorrhage from the vena cava are listed.

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ARTERIOVENOUS ANASTOMOSIS IN TRAUMATIC VASCULAR LESIONS*

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VASCULAR injuries are not an uncommon complication of trauma as seen in civilian practice. Their etiology may be from either external or internal violence and consequently their presence must be sought for in all fractures of an extremity as well as blunt trauma to the chest or abdomen. The more obvious external causes with external bleeding as seen in gunshot, knife or wounds due to flying débris are most easily diagnosed. Traumatic vascular lesions are conveniently classified in three groups: (1) *Immediate group:* hematomas, bruised limb, laceration of vessels, injury of vessels with loss of substance; (2) *delayed group:* pulsating hematomas, traumatic aneurysms, traumatic arteriovenous fistula, arteriolar thrombosis secondary to arterial interruption; (3) *special group:* stab wounds of the heart and great vessels.

With this classification we wish to emphasize some of the principles involved. It is important that any surgeon handling traumatic cases be equipped to take care of any vascular lesion he may encounter. The equipment necessary to do so is simple, and no specialized instruments are required to do adequate suturing of blood vessels. We are in the habit of using No. ooooo silk with an everting mattress type of stitch, but adequate blood vessel surgery can be done with any fine non-absorbable suture on small round needles.

We have believed for a number of years that all vessels should be reapproximated if at all possible. A small artery, such as the radial, is obviously destined in some cases to become thrombosed after suture. However, in a great percentage a perfectly adequate suture can be done with a functional result. Practice in re-establishing the continuity of smaller vessels makes the suture of large blood vessels easy.

Rose, Hess, and Welch,[1] in reporting their experience in the last war, found that a portion or a total limb became gangrenous following interruption of the axillary artery in 40 per cent, the brachial in 31 per cent, the femoral in 82 per cent and the popliteal artery in 77 per cent. Their results clearly demonstrated that arterial interruption is destined to be followed in a high percentage of cases by gangrenous changes in the distal limb. It should be emphasized that trauma to the arteries is not alone in importance, since vascular injuries of the venous channels, although not usually carrying as serious a consequence, lead to morbidity and mortality if not properly cared for. The problem of the proper care of a hematoma is an excellent example. A large hematoma is a sign of possible serious underlying vascular trauma and should, we believe, be investigated with as little loss of time as possible. Large hematomas, particularly in the lateral thigh of females, if left alone or aspirated, lead to pseudocyst formation with infection and necrosis of the overlying skin. Liquefied hematomas necessitate many days of hospitalization and a difficult delayed closure. Better results with a lessened morbidity can be obtained by immediate incision, ligation of bleeding vessels and a delayed closure in five or six days. Bleeding into tissues from a fair sized vein can be quite exsanguinating and the pressure developed in the tissues cannot always be depended upon to stop venous bleeding. When an artery is transected, the ends tend to retract, leaving a gap and these are frequently difficult to approximate. Furthermore, trauma often tends to cause damage for a distance from the site of the injury. It is important that continuity of the vessel be re-established through normal tissue. Frequently it is possible to free the artery for a distance above and below the injury to allow approximation without tension after the obviously damaged portion is resected.

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If this is not possible, other means must be taken to bridge the defect. We have had no experience with the use of plastic tubes as described by Mustard[2] or with vitallium® tube vein grafts as described by Blakemore, Lord and Stefko,[3] or with banked arterial grafts.[4] We have, however, quite satisfactory functional results with the use of autogenous free vein grafts in the repair of arterial or venous injuries.

There are sufficient data in the literature to indicate that these grafts survive and function well. Quite recently we have studied vein grafts after two months in laboratory animals and found them functioning. Murray[5] in 1940 reported functional survival of vein grafts in dogs for 290 days. Murray,[5] Johnson,[6] Holden[7] and Freeman[8] have reported surviving and functioning vein grafts in man for many months. We have utilized the long saphenous or superficial femoral vein to repair defects too large for direct approximation. The following case illustrates good function in an artery grafted with a 15 cm. segment of vein.

CASE REPORT

H. B. was a thirty-five year old policeman who was admitted to Receiving Hospital on October 29, 1948. He had been shot in the left thigh by a shotgun blast. The wound had taken away about 6 inches of his left femoral artery and vein and overlying muscle and skin. A 15 cm. length of his right saphenous vein was used as a free vein graft to re-establish continuity of his left femoral artery. Heparin, antibiotics and repeated paravertebral blocks were administered for twelve days post-operatively and he was discharged home with good dorsalis pedis pulses bilaterally. The left lower limb was swollen and necessitated supporting bandage. On February 12, 1949, the patient re-entered the hospital for revision of the scar of the left thigh. His left foot and leg were slightly swollen but the pulses good. The skin temperature was slightly higher on the left than on the right. On October 30, 1949, the patient returned for follow-up, walking without a limp, with good leg warmth and motion. Pulsation could be felt the full length of the scar since skin overlay only the femoral vessels, the rectus femoris having been shot away in this area. On April 15, 1950, the patient still was in good condition, asymptomatic and without swelling of the limb.

A problem which is always troublesome and which often spells disaster, so far as the limb distal to the injury is concerned, is that of small clots formed at the site of injury being forced into the distal vessel. Even though great care is exercised in removing the clot from the distal artery, this is often not adequate to remove the smaller clots. After the vessel is sutured and the blood is allowed to flow through the artery these are forced into the smaller arteries and cause occlusion of the vessels, often lodging in terminal vessels, especially in the toes. If a toe was all that was lost in this process, this would not be too great a sacrifice but usually the clot tends to propagate proximally. In one such case we were forced to do a high thigh amputation despite a well functioning arterial tree in the lower extremity for a week.

Heparinization has not been a corrective for this clot in our hands. For a time we used heparin following such a procedure, but gave it up because we did not believe it was necessary (except for injection of heparin into the distal vessel at time of surgery) and because it tends to cause bleeding at the suture line in the vessel and in the wound. We believe that heparinization of the patient is not necessary if a good intima-to-intima approximation is obtained; in fact, we believe it may be harmful.

In cases in which the distal artery becomes thrombosed causing a sudden interruption of this portion of the vascular tree, before any collateral circulation can adequately carry the supply around the obstruction, the problem becomes urgent. If one waits for the collateral to develop, irreversible damage is usually done to the distal limb necessitating amputation. Clinically these people present themselves with a painful, swollen distal limb which is cool on examination, without pulsation, with areas of early skin necrosis, and on surgical exploration a negative Henle-Coenen (no back flow from distal artery limb) is present. These are the cases in which we believe an arteriovenous shunt has definite merit. To cite a case, a young man entered Receiving Hospital with a popliteal aneurysm completely occluding the vessel. Early gangrenous changes had taken place in the leg. Accordingly an end-to-end anastomosis of the popliteal artery and vein was made. Within twenty-four hours the foot became pink and was without pain. The gangrenous areas demarked well and healed rapidly. The man has been working a year now in an auto plant without difficulty.

Utilization of a vein to carry arterial blood is not a new concept, it having been proposed

and used clinically by San Martin y Satrustegui[9] in 1902. Between 1906 and 1913 after Carrel and Guthrie's original report[10] many experimental and clinical studies appeared in the German, English and American literature. Berhneim[11] in this country, Davies in England[12] and Coenen[13] in Germany were the main contributors.

We became interested in this problem in relation to peripheral vascular occlusion after Beck[14] reported the use of an arteriovenous shunt in coronary artery disease. Shortly thereafter we encountered a case in which it seemed an arteriovenous fistula was the only solution. There were many problems that seemed to be insurmountable from the outset, the first being whether or not the valves of the veins would obstruct the flow. This, as Carrel[15] showed, was not the case and we have confirmed this. Another was whether or not an arteriovenous anastomosis which had the proximal venous limb tied produced an arteriovenous fistula effect. Holman[16] in 1924 showed that the pathophysiologic agent in arteriovenous fistula was an elevated blood volume. By use of this fact nine dogs were checked to see if arteriovenous shunts produced elevation of blood volume. Of these nine dogs only three anastomoses remained patent three to six months later, and these did not show any elevation of blood volume. The fact that these shunts did not remain patent was simultaneously being observed clinically. Of the first nineteen patients operated upon only two had anastomoses remaining open long enough to be of lasting benefit. In the laboratory meanwhile several pertinent facts had come to light. One was that the pressure and direction of flow of the blood within a fistula and shunt differed greatly. In a shunt the blood pressure within all three limbs of the anastomosis rose to systolic arterial pressure and the blood flowed distally. In a fistula, as Holman[17] and Robertson[18] have shown, the pressure drops in the distal arterial limb and the blood flows centrally, while in the distal venous limb the blood pressure rises to approximately one-half the arterial pressure and the blood flows distally. This means that actually less arterial blood is delivered to a distal part below a fistula while the reverse is true of a shunt.

Since in the laboratory and in man arteriovenous shunts regularly closed, it was apparent that some other approach was necessary. Arteriovenous fistulas do not tend to close. Accordingly arteriovenous fistulas were prepared by side-to-side anastomosis of the artery and vein. After three to four weeks this was converted into a shunt by a second operation in which the proximal venous limb was

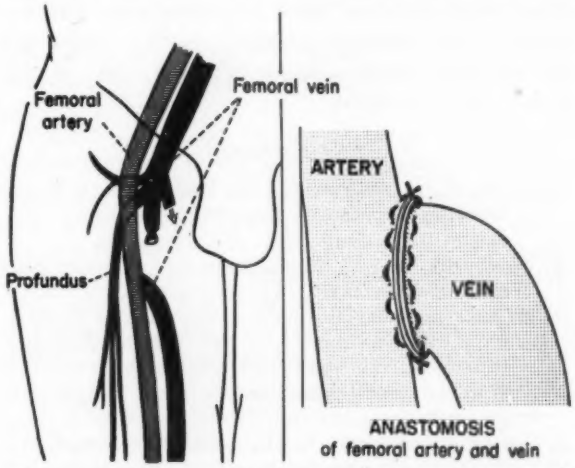

FIG. 1. Diagrammatic representation of the final anastomosis.

divided and ligated. (Fig. 1.) In the laboratory this two-stage construction gave 80 per cent patent functioning anastomoses one to two months after the second stage. In our hospital three cases have been done by this two-stage procedure. Only two of these were for sudden occlusion, one from a gunshot wound through the femoral artery, the other an arteriosclerotic occlusion. The first died from kidney shutdown before a second operation, and the other case has just been done with limitation of progression of the patient's gangrene and a warmer foot.

What the true explanation of the effect of an arteriovenous shunt is remains obscure. It may be that small arteriovenous anastomoses are opened which shunt the blood back to the arterial side before the blood goes through the capillary bed. Certainly it is difficult to believe that the circulation down to and through the capillary bed is completely reversed. That a fistula is the strongest stimulus for collateral development has been shown and perhaps this is the means in which a shunt acts without the elevation of blood volume. The investigation of this fundamental problem is still in progress.

CONCLUSION

We would like to reiterate that (1) traumatic vascular lesions are commonly seen in civilian

practice and that an adequate appreciation of their likely presence is necessary to any one dealing with traumatic cases; (2) the suturing of a sectioned vessel requires no special apparatus; (3) autogenous free vein grafts can be used with good expectation of functional survival and (4) arteriolar thrombosis is a definite clinical entity and can be treated most adequately by use of an arteriovenous shunt.

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TRAUMA TO THE ARTERIAL-INSUFFICIENT FOOT*

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MINOR trauma to the normal foot is rarely provocative of serious consequences. On the contrary, in the foot deprived of an adequate arterial circulation, minimal insults may eventually be followed by the loss of a limb. When the patient employs injudicious therapy, the situation may be unfortunate; but when a physician is responsible for trauma to the arterial-insufficient foot, the result may truly be tragic. Let us cite some of the outstanding examples which we have observed in private practice during the past few years.

CASE REPORTS

CASE I. A. W., a thirty-seven year old lawyer with known diabetes and nephritis, twisted his left ankle stepping from a curb and developed pain, swelling and ecchymosis. An x-ray showed no evidence of bony injury and the advice from his physician included elevation of the limb and the application of a hot water bottle to the ankle. Within twenty-four hours a large blister developed on the dorsum of the foot with subsequent infection and gangrene of all of the toes and heel. Eventually, in spite of the best surgical care, supracondylar amputation was necessary.

CASE II. S. A., a sixty-eight year old housewife, a known diabetic, whose right leg had been amputated ten years previously, developed a painful callous on the plantar aspect of the left foot. Her physician treated the callous by the application of trichloracetic acid. In forty-eight hours an eschar developed which was followed by gangrene of the distal half of the plantar surface of the foot. Eventually, a supracondylar amputation of the left leg was required.

CASE III. I. B., a seventy year old housewife, a known diabetic of ten years, lacerated the plantar surface of her right foot by stepping on a broken bottle. There was slight bleeding and her physician applied a tourniquet high on the thigh and after one and one-half hours, extracted a piece of glass from a 4 cm. laceration and sutured the wound. The tourniquet was then removed. Severe pain, blanching and coldness of the foot promptly developed. In a few days gangrene of the fourth toe and heel developed, associated with sloughing of the wound. A lower leg amputation was subsequently carried out.

CASE IV. H. C., a sixty-two year old salesman, a known diabetic, developed an infection in the web space between the fourth and fifth toes in a setting of an active fungus infection. For eight weeks daily probing of the wound, without adequate drainage, led to such a deterioration of the local situation that, when seen by one of us, an x-ray showed osteomyelitis of the fifth toe and metatarsal bones. A large collection of pus was present and the blood culture was positive for Staphylococcus aureus. In spite of adequate drainage death occurred twenty-four hours postoperatively.

CASE V. M. T., a sixty-eight year old housewife, developed an infection of the first toe due to an ingrown nail. Her physician recommended that she soak her foot in water "as hot as she could stand." Within one week gangrene of two toes developed, and in spite of hospitalization, paravertebral procain block and other measures, including an oscillating bed, gangrene spread, and a lower leg amputation was required.

CASE VI. M. H., a fifty-seven year old garage owner, developed an infected ulcer of the lateral aspect of the distal phalanx of the right great toe. His physician treated the foot with diathermy, which was followed by a sloughing ulcer over the first metatarsophalangeal joint. On conservative management the ulcer of the toe healed but all measures failed in the prevention of an extension of the ulcer into the metatarsophalangeal joint, which shortly involved the two adjacent bones by an osteomyelitic process. After three months of hospitalization the patient was discharged well, only after an amputation of the great toe and distal third of the first metatarsal bone had been done, and later followed by a split-thickness skin graft.

CASE VII. N. P., a fifty year old leather dealer, developed intermittent claudication of the right calf on walking one and one-half blocks. In one of the outstanding hospitals in New York he was advised to soak his foot alternately in hot and cold water. Following one of the hot water soaks two blisters formed on the right heel and then developed into indolent ulcers. After three weeks of hospitalization he was seen in consultation by one of us, and examination showed absent pulsations in the right

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foot, rubor on dependency, pallor on elevation and a venous filling time of twenty-five seconds. The ulcers were débrided under spinal anesthesia, tepid saline foot soaks employed and smoking discontinued. The ulcers healed rapidly in three weeks, and within two months claudication had disappeared.

CASE VIII. E. N., a sixty-eight year old housewife, sustained a supracondylar fracture of the right femur. An orthopedic surgeon applied Russell traction with longitudinal moleskin reinforced by circular adhesive strips. The foot was elevated approximately 6 inches above heart level. The adhesive slipped 2 inches by the eighth hospital day, causing the circular adhesive strips to impinge on the foot at its junction with the ankle. Gangrene of the foot developed within twenty-four hours, requiring amputation above the knee through the fracture site.

METHODS OF EVALUATION OF ARTERIAL CIRCULATION TO THE FOOT

Prior to the institution of any form of therapy to the foot, a careful clinical appraisal of the circulation must be carried out. Such an evaluation is simple, requiring no elaborate apparatus. An oscillometer is useful but not an essential part of the study. The following observations are important:

1. In the history it is important to elicit whether there has been intermittent claudication, which is an excellent index of diminished arterial circulation, in contrast to the symptom of pain in the legs at rest but not with exercise, the latter having many causes not related to arterial insufficiency.

2. Palpation for pulsation of the posterior tibial and dorsalis pedis arteries. If these are absent, the popliteal and femoral arteries should be palpated for pulsation.

3. The color of the foot should be observed in the horizontal position as well as in the elevated and dependent positions. When there is marked arterial insufficiency, cyanosis and rubor may be evident when the foot is at heart level. However, in lesser degrees of arterial insufficiency pallor on elevation of the foot 18 to 24 inches above the heart level will usually be noted. The principle underlying this phenomenon is as follows: When the main artery is either partially or completely occluded, the collateral circulation may bring sufficient blood to the foot when its flow does not have to work against gravity. However, elevation may interfere with the feeble arterial pressure in the collaterals to such an extent that arterial blood cannot reach the capillaries, and hence pallor rapidly becomes evident. Rubor on dependency also reflects the degree of arterial insufficiency by virtue of the fact that the low arterial pressure in the collaterals cannot force the blood from the arterioles and capillaries into the venous side; hence the hemoglobin in the sluggish capillary circulation loses its oxygen and reduced hemoglobin results in the cyanotic, ruboric state.

4. The temperature of the foot and toes in a warm environment may be readily appraised by the dorsal aspect of the fingers of the examiner and compared with the opposite foot and leg. If arterial insufficiency is significant, the foot will be cooler than normal under these circumstances. An inflammatory reaction may give some warmth to the foot which may lead to a false impression of the circulation.

5. The venous filling time, in the absence of varicose veins with incompetent valves, usually is less than ten seconds. This test is carried out by elevation of the legs, with the patient in the recumbent position, which empties the veins, and then placing the feet in a dependent position by having the patient sit on the side of the examining table. When the arterial circulation is impaired, the veins may not fill for fifteen to sixty seconds because of the time it takes for the blood to pass from the collateral arterial vessels through the capillaries and then to the veins.

6. Capillary refill is readily determined by pressing on the toes with a finger and observing how quickly a pink color returns to the skin. If arterial circulation is markedly impaired, several seconds may elapse before the color returns.

7. Nail growth usually reflects the state of the arterial circulation and sluggish growth often is associated with an impaired arterial supply.

8. In significant degrees of chronic arterial insufficiency, the foot may appear "skeletonized" because of loss of subcutaneous tissue.

9. Oscillometry is valuable as an adjunct in determining patency of the main arterial channels. It is not an essential part of the examination but is easy to perform and the apparatus is readily available.

TYPES OF MINOR TRAUMA TO THE ARTERIAL-INSUFFICIENT FOOT WHICH MAY BE OF SIGNIFICANCE

Improper use of heat, such as hot soaks, may, as illustrated above, change a relatively minor infection into a major loss of a limb (Cases v and vii). Tepid saline soaks are valuable in the treatment of infection of the foot, but the temperature should not be above 95°F. (35°C.) and this should be checked by a bath thermometer. We have seen one case of a thermal burn occurring in a man supposedly taking baths checked with a faulty thermometer, whereas actually the baths were over 100°F. and the patient did not rely on the temperature sense of his fingers. Although it is important to take the temperature with an instrument, it is more essential for the patient to check the warmth of the solution with his fingers.

Exposure to cold may lead to frostbite and gangrene in individuals suffering from an impaired arterial circulation. Therefore, considerable effort should be made to avoid unnecessary exposure to a cold environment unless protection to the feet is afforded.

Improper care of the nails may lead to ingrown toenails and to trauma to the soft parts of the adjacent toes by an inadequately trimmed nail (Case v).

Fungus infection is the bête noir of the patient with arterial insufficiency. This ubiquitous malady frequently serves as the point of entry for secondary bacterial invaders which result in cellulitis, a serious threat to the arterial-insufficient foot. It is, therefore, vital that patients with an impaired circulation utilize measures to control the fungus infection (Case iv).

Plantar callouses are common in the diabetic patient with flattening of the metatarsal arch. Improper use of caustics and improper trimming of the callous may lead to infection or gangrene (Case ii). In the individual with a normal circulation trauma of this nature will usually cause little difficulty.

Diathermic treatment to the foot should never be applied under any circumstances unless the arterial circulation is normal (Case vi).

Injudicious probing of wounds and inadequate drainage are, in general, poor surgical practice and may lead to serious complications if the arterial supply is impaired (Case iv). Collar-button abscesses and space infection are frequent in the diabetic foot and require prompt and adequate drainage.

The use of a tourniquet, other than to save life from an exsanguinating hemorrhage which has not been controlled by a pressure dressing, should be deplored. Case iii is illustrative of the unnecessary and evil use of this measure. Further, amputation, when necessary in this group of patients, should be performed without a tourniquet.

Considerable care should be exerted in applying elevation of an extremity, the blood supply of which may be impaired, in the treatment of a fracture. Case viii, an elderly woman with a supracondylar fracture of the femur, was treated with elevation in Russel's traction and developed gangrene of the foot because of an associated arterial insufficiency.

Pressure blisters caused by improperly fitted shoes may result in serious difficulty when the blood supply is diminished to the foot. Such patients should exercise care in the selection of shoes which do not cause pressure on the toes or elsewhere.

The use of procaine with adrenalin should be avoided in operations on the extremities, and procaine alone in large amounts under pressure may result in gangrene, particularly in individuals with impaired arterial flow.

SUMMARY

It has been the purpose of this paper to point out the simple and yet effective ways for the evaluation of the arterial circulation to the foot and to emphasize the types of trauma which may lead to serious consequences. Some forms of trauma stem from improper advice given by physicians who have not determined that the foot was inadequately supplied by a normal arterial blood flow. Illustrative cases have been cited which point up the types of trauma and the unfortunate consequences, the majority of which could have been avoided.

TRAUMATIC CAROTID-CAVERNOUS SINUS ANEURYSM

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COMMUNICATION between the internal carotid artery and the cavernous sinus is a rare complication of head injury. In our series of head injury cases we encountered five patients with this condition, an incidence of one patient in approximately every four hundred who had sustained head trauma. This estimation of the frequency of occurrence is probably much too high, because the milder and uncomplicated cases of head injury are often not seen by the specialist. Even though this artery-vein communication is a relatively simple mechanical condition, it may be attended by great hazards to the patient, in spite of the best medical and surgical treatment now known.

According to Dandy[2] about three-fourths of the internal carotid-cavernous sinus aneurysms result from trauma. Rupture of congenital aneurysms occurring in the cavernous portion of the internal carotid or weakening of the arterial wall from arteriosclerotic patches may lead to spontaneous communication.

The anatomic relationship of the internal carotid to the cavernous sinus has no parallel in the human body, for nowhere else does an artery pass directly through a vein. Another factor which may predispose to a communication between the internal carotid and the cavernous sinus is that the walls of the carotid, in its intercavernous course, are weaker than elsewhere; certainly, the artery is less well supported in that area. At their intracranial point of approximation the cavernous sinus and the carotid artery are fixed so a tear in the walls of these structures could easily occur as a result of head trauma. Naffziger[8] was of the opinion that the development of the arteriovenous communication is often a relatively slow process. He thought that the bruised wall of the artery gradually becomes weaker and thinner and finally ruptures. In support of that idea he pointed out that the average time from injury to appearance of aneurysmal symptoms is about twenty-one days. Six months elapsed from the date of injury to the onset of eye symptoms and bruit in one of our patients.

SYMPTOMS AND DIAGNOSIS

While the initial lesion of an internal carotid-cavernous sinus communication is an opening in the wall of the internal carotid as it passes through the cavernous sinus, other changes soon occur in surrounding structures. Arterial blood pouring into the venous sinus, results in engorgement of the sinus; consequently, there may be a reversal of the venous flow in the ophthalmic veins and their tributaries. Congestion of the conjunctival and episcleral vessels, edema of the lids and pulsating exophthalmos result. Exophthalmos is always associated with temporal displacement of the globe in the orbit. Some pulsation of the exophthalmic eye can be observed in almost all cases, but gross displacement of the globe with each systole is unusual. Pulsating exophthalmos is not invariably the result of carotid-cavernous sinus communication. Vascular tumors of the orbit, aneurysm of the ophthalmic artery or of the extracavernous portion of the internal carotid may also cause pulsating exophthalmos. Loss of the orbital roof because of trauma, surgical removal or encephalocele are other causes. Intracranial tumors, even though remote from the orbit, likewise may cause pulsating exophthalmos. For example, within the last year we have observed pulsating exophthalmos in a fifteen-year-old girl with a meningioma of the left parietal area. The slowly developing pressure, resulting from the growth of the tumor, had destroyed the orbital roofs and bilateral pulsating exophthalmos had resulted.

If the pressure is sufficiently high or the intercavernous or basilar sinuses open wide enough, the opposite cavernous sinus may become distended and pulsating exophthalmos may occur on both sides. Sattler[9] found bilateral pulsating exophthalmos present in 17 per cent of 235 cases which he studied. Dandy and Follis[5] reported a case in which the patient had no

exophthalmos or pulsation on the side of the fistula, while marked exophthalmos and pulsation were present on the opposite side. They inferred that pulsating exophthalmos had been precluded on the side of the fistula by total thrombosis of the ophthalmic vein. Necropsy proved this assumption to be correct. They pointed out that the choice of the side for the surgical attack cannot depend upon which has the more marked pulsating exophthalmos, but rather upon which side carotid compression alters the bruit, both subjectively and objectively.

A symptom particularly annoying to the patient is the bruit. A bruit, however, does not at all times mean the presence of a carotid-cavernous sinus aneurysm nor, for that matter, the presence of any type of intracranial aneurysm. Two of our patients with intracranial tumors were noted to have bruits audible not only to the patients but to the examiner. One of these patients was a twenty-three year old white female whose chief complaint was a "noise in the head." She had been seen elsewhere and, because of the bruit, an arteriogram had been done. When the arteriogram failed to visualize an aneurysm, no surgery was advised. We later carried out an air study which revealed the tumor. Removal of a meningioma stopped the bruit and, up to the present time (twenty-two months following operation), there has been no recurrence of the bruit. The other patient, a seventy-five year old male, had a history which suggested cerebrovascular accident. He, too, complained of a noise in his head, and a bruit could be distinctly heard. Because of his age and poor general condition no surgery of any type was performed. Autopsy subsequently revealed a large glioblastoma multiforme. Probably if the stethoscope were routinely applied to the head in patients who were suspected of having intracranial tumors, more bruits would be detected.

One of the most common symptoms is that of diplopia which, in our opinion, seems to be attributable in some patients to mechanical limitation of rotation of the eye, associated with displacement of the globe and edema of the orbit, rather than to pressure on the nerves of the extra-ocular muscles as is generally assumed. The function of other intracranial nerves may be impaired. Sugar and Meyer[11] pointed out that the first eight cranial nerves may be involved by direct effects of original trauma, by the direct pressure of the dilated vessel, by hemorrhages or venous congestion and by stretching because of exophthalmos.

A common finding which has received little or no attention in the literature is increased ocular tension. A large number of the reported cases of carotid-cavernous sinus communication have been from general and neurologic surgeons who have disregarded the intra-ocular tension. Fundoscopic examination reveals venous engorgement and diminution in venous pulsations because of increased pressure in retinal veins. Also, there may be retinal hemorrhages but only occasionally papilledema. Increased ocular tension may be an explanation for the relative infrequency of papilledema in patients with carotid-cavernous sinus communication.

The diagnosis of carotid-cavernous sinus communication can usually be made very easily from symptoms and clinical signs. If there is any question regarding the nature of the lesion, an arteriogram may be performed. This test seemed essential in only one of our five patients. Thorotrast was injected into the carotid artery, and the roentgenograms showed a shunt of the opaque material into the cavernous sinus.

CASE REPORTS

CASE 1. Mr. D. McL., a thirty-one year old logger, was first seen seven months after he had been hit by a falling tree on June 22, 1944. He had sustained a right frontal skull fracture and had been unconscious for one week. When he regained consciousness, he had a severe left-sided headache which had persisted since the accident. Also, the left eye had remained bloodshot. Double vision and a buzzing noise in the head had bothered him from the time that he had regained consciousness. Examination revealed swelling of the left periorbital tissues, engorgement of the veins of the conjunctiva and sclera, exophthalmos and a bruit. The bruit could be stopped by digital pressure over the left common carotid artery, and closure of the artery for seven minutes produced no neurologic symptoms. The retinal veins in the left eye were tortuous and there was a choked disc of one diopter. Uncorrected visual acuity was 20/40 in each eye. Ocular tension was not recorded. On February 27, 1945, under local anesthesia the left common, internal and external carotid arteries were exposed. A rubber-shod clamp was placed on the internal carotid artery for forty-five minutes after which it was ligated and cut. The external and common carotid arteries were not ligated. The bruit stopped immediately after the operation and, within a few days, the congestion about the left eye became very

much less marked. The patient has been seen at various intervals since the operation, the last time being on June 12, 1950. He has had no recurrence of the bruit. There was a very slight degree of exophthalmos of the left eye. Ocular movements were normal and he had no double vision. The retinal veins in the left eye may have been a little more full than those in the right. No papilledema was present. Vision in each eye was normal. He was working and had no complaints.

CASE II. Mr. R. W., aged twenty-four years, was first seen on December 1, 1948. He had sustained a relatively mild head injury in an automobile accident on December 15, 1947. He had not been unconscious. His nose had been fractured but there had been no skull fracture. Within a few days he had recovered and experienced no symptoms until May, 1948, when he first noted that his left eye appeared "bloodshot." In June for the first time he had heard a noise synchronous with his heartbeat, and in August the left eye had become a little more prominent than the right. With the onset of these symptoms, mild, left-sided headache developed. Examination revealed an intelligent, cooperative, twenty-four year old man in excellent physical condition. His blood pressure was 165/95. Conjunctival injection of the left eye was marked. There was 5 mm. of exophthalmos of the left eye and a pulsation was visible. A slight limitation of rotation of the left eye was present, and the patient complained of intermittent diplopia. The visual acuity with glasses was 20/25 in the left eye and 20/20 in the right eye. The discs were not choked but the left retinal veins were engorged. Ocular tension in the right eye was 16 mm. and in the left eye 32 to 34 mm., Schiötz. Some bedewing of the corneal epithelium seen in glaucoma was present. Compression of the left common carotid artery in the neck stopped the bruit and was well tolerated for five minutes; no numbness or weakness of the right extremities and no aphasia was in evidence. At the end of carotid compression for five minutes, however, he said that he had completely lost vision in the left eye. Upon releasing the pressure the vision quickly cleared.

On December 7, 1948, the left carotid arteries in the neck were exposed under local anesthesia. Rubber-shod clamps were applied to the common and external carotid arteries and after thirty minutes there were no untoward effects. No loss of vision was noted in the left eye, as had been experienced when the carotid in the neck had been manually compressed. The common and external carotid arteries were ligated with heavy black silk tied over pieces of preserved fascia lata. On the day following operation there was some decrease in the exophthalmos. Visual acuity remained unchanged. The intra-ocular tension in the left eye had been reduced to 12 to 14 mm. By December 24, 1948, the patient had noted some blurring of vision in the left eye. Fundoscopic examination revealed considerable edema of the retina, diminished arterial pulsation and slight cyanosis. A large number of cotton-wool patches were noted throughout the fundus but particularly around the macular region. Visual acuity in the left eye was reduced to 20/70 with glasses. By December 31, 1948, there had been considerable clearing of the retinal edema. Visual acuity in the left eye had returned to 20/30; there was 2 mm. exophthalmos of the left eye and the ocular tension was normal in both eyes. On April 1, 1949, he reported that one week before that visit, following a hot steam bath, he had experienced a numb sensation in the right arm and leg that had lasted four days and then disappeared. He had noted no weakness and neurologic examination on April 1, 1949, revealed no abnormal findings. The patient was last examined on June 17, 1950. He stated that he had an occasional dull, aching pain in the left side of his head, especially in the mornings. He also said that occasionally he had a transient, tingling sensation in the right arm and the right leg; otherwise, he felt well and was working every day. His blood pressure was 138/95. There was slight engorgement of the conjunctival veins of the left eye and an exophthalmos of approximately 3 mm. on the left side. No pulsation of the left eye could be noted. Fundoscopic examination revealed no choking of the discs and no hemorrhages or exudates but the veins in the retina of the left eye were engorged. Visual acuity was 20/20 in each eye with glasses. Ocular tension was normal. No neurologic abnormalities were noted.

CASE III. Mr. L. E. R., aged twenty-three years, was first seen on the day following a logging accident. On September 27, 1948, he had been struck by a rolling log and had sustained a fracture in the right parietal and basal regions of the skull, with spinal fluid drainage from the right ear. He also had a fracture of the right clavicle, fracture of the second, third and fourth ribs on the left side with pneumothorax, injury to the right shoulder, laceration of the chin and left axilla and a contusion of the left thigh. At first he was hospitalized in a small hospital near the scene of the accident. His condition became worse and a spinal puncture the day following the injury revealed that he had meningitis. He was transferred to Good Samaritan Hospital in Portland, Oregon. He was deeply stuporous for several days but finally regained consciousness. It was then discovered that he had weakness of the left external rectus muscle. He complained of double vision. Approximately one month after the injury he was able to leave the hospital wearing a patch over one eye because of diplopia. He was thereafter seen in the office approximately once a month. The extra-ocular movements of his left eye improved; and, finally, he had

little or no double vision. When he came to the office on February 4, 1949, he stated that within the last few weeks he had noted some congestion of the left eye and that the left eye was becoming more prominent. Headaches had also started a few weeks prior to February 4th and were located about the left eye. He observed that the vision in the left eye had become blurred, even though he closed the right eye. He was then quizzed specifically regarding a bruit; and he said that he had noted a buzzing in his head ever since he had regained consciousness following the accident but had not paid much attention to the noise and had never mentioned it to anyone. Examination showed his blood pressure to be 126/58 and the pulse was 76. The exophthalmos on the left measured 6 mm. and there was pulsation of the left eyeball. Considerable edema of the conjunctiva and the lids of the left eye was present. Fundoscopic examination showed slightly engorged retinal veins bilaterally, more marked on the left side. The ocular tension in the right eye was 14 mm. of mercury and in the left eye 28 mm. (Schiötz). Visual acuity in the left eye was 20/20 and in the right, 20/15. Auscultation revealed a bruit heard best in the left temporal region. Compression of the left common carotid artery stopped the bruit and was well tolerated for ten minutes.

On February 19, 1949, under local anesthesia, the carotids in the left side of the neck were exposed at the bifurcation. Compression of the left common and external carotid arteries for thirty minutes produced no symptoms. These arteries were tied with heavy silk over preserved fascia lata. On February 21, 1949, the exophthalmos of the left eye had been reduced to 2 mm. Extra-ocular movements were full. The ocular tension in the left eye was 10 mm. From February 23rd to February 26th there was progressive retinal edema in the left eye. Cotton-wool patches and cyanosis of the retina developed with reduction in the visual acuity to 20/200 in the left eye. On February 26, 1949, the ocular tension in the left eye was 12 to 13 mm. and in the right eye 17 to 18 mm. On March 28, 1949, examination of the left eye showed that the visual acuity was 20/40; the ocular tension was 12 mm. and there was a 3½ mm. exophthalmos. Some edema and several small hemorrhages remained in the left retina and a faint bruit could still be heard. On July 8, 1949, the left ocular tension was 13 mm., the right 18 mm. Some retinal edema persisted and there were many capillary aneurysms. On September 25, 1949, the vision was recorded as 20/15 in the right eye and 20/20 in the left; there was 3 mm. exophthalmos in the left eye and the ocular tension in the left eye was 17 mm. The patient was last seen on June 20, 1950. He reported that he had been feeling perfectly well. He was married in November, 1949, and has been working steadily in a sawmill. There was no subjective or objective bruit. He still had approximately 2 mm. exophthalmos in the left eye. There was slight injection of the left episcleral veins and there was one large dilated vein in the left temple region. Fundoscopic examination showed some engorgement of the left retinal veins. Visual acuity was normal in each eye. He experienced no double vision. The intraocular tension was normal.

Case IV. Mrs. L. E., aged twenty-seven years, was first seen on September 26, 1949. On June 30, 1949, she received a "cerebral concussion" and a scalp laceration on the left forehead when she was in an automobile accident. She believed that she did not fully regain consciousness for six hours. Roentgenograms of the head showed no skull fracture and spinal puncture revealed nothing abnormal. After remaining in the hospital for one week she was dismissed to her home, but was re-admitted to the hospital five days after her dismissal because of increasing severity of the headache in the left frontal and suboccipital regions. Occasionally, following the accident she had been bothered with double vision, and ever since the accident she had noted a "dripping" sound in the left ear. The patient was tearful, apprehensive and tremulous. The blood pressure was 110/60. A loud bruit could be heard over the entire frontal area of the skull but was more prominent on the left side. Pressure over the left carotid stopped the noise and she tolerated compression of the left carotid without developing any neurologic signs on the right side of the body. There was pulsating exophthalmos of the left eye of 3½ to 4 mm. The lids and conjunctiva were edematous and there was a slight ptosis of the left eyelid. Rotation of the left eye was limited to about 15 degrees. The tension in the left eye was 22 to 24 mm. and in the right eye 15 mm. Visual acuity was normal in each eye and no papilledema was present.

On September 29, 1949, an arteriogram was done on the left side which revealed a communication between the left internal carotid artery and the cavernous sinus. The left common carotid was clamped with a rubber-shod clamp for thirty minutes, after which the common and external carotid arteries were ligated with braided silk over fascia lata. She had a smooth postoperative course. The bruit stopped immediately. Three days after operation the ocular tension in the left eye was 12 mm.; two weeks after operation it was 15 mm. She completely recovered ocular movement. A few days after ligation of the common and external carotid arteries the patient experienced an episode during which she had difficulty in speaking. The aphasia cleared in ten minutes and she had no other difficulty. She did not have any loss of visual acuity and did not develop retinal edema, cotton-wool patches or hemorrhages. The patient was last examined on June 5, 1950, when she reported that since the operation she had had transient episodes of weakness

or a tired feeling in the right side. At times the right side of the body felt numb. These episodes lasted from a few seconds up to ten minutes. She had had no recurrence of the bruit in the head. Neurologic examination revealed no abnormalities. The blood pressure was 130/80. Ocular movements were normal and there was no ptosis of the left eyelid. Fundoscopic examination showed that in the left retina there were a few tiny capillary aneurysms in the superficial layers around the nervehead. Measurement with the ophthalmometer showed that there was no remaining exophthalmos of the left eye, and the intra-ocular tension was 16 mm. in each eye. Visual acuity was 20/20 in each eye. Field examination was normal.

CASE V. Mr. K. McL., aged twenty-nine years, was admitted to the Multnomah County Hospital on January 30, 1950. Eighteen days prior to the date of admission he was involved in a street fight and his head was struck repeatedly against the pavement. He was taken to a hospital where lacerations of the right upper and lower lids were sutured. He was dismissed from the hospital the same evening, his only complaints at that time being pain around the right eye, generalized weakness and inability to see because of swelling of the eyelids. Two days after injury he was admitted to another hospital because of continuation of pain around the right eye. Roentgenograms of the head showed no skull fracture. Extra-ocular movements were normal at that time. After remaining in the hospital for four days he was again dismissed. The right eye became more painful and swollen. Upon admission to the Multnomah County Hospital he stated that he had noted double vision and a noise in his head from the time of injury. Inquiry into his past history revealed that he sustained a head injury and skull fracture at the age of seven years when his head struck a curb. At the age of eighteen he was hit behind the right eye and suffered another skull fracture. Examination revealed a well developed, well nourished twenty-nine year old white male. The blood pressure was 115/80. He had a complete right ophthalmoplegia. There was marked chemosis of the right eye and moderate chemosis of the left eye. The right pupil was larger than the left but both reacted to light. There was ptosis of the right eyelid. Auscultation revealed a bruit over and around the right eye which was obliterated by pressure on the right carotid artery. Pressure on the carotid for seven minutes, while relieving the bruit and the right orbital pain, produced no untoward effects. There was an exophthalmos on the right side of 3 or 4 mm. The visual fields were full. Visual acuity in the right eye was 20/50 and in the left eye was 20/30. The ocular tension was 23 mm. in the right eye and 15 mm. in the left eye. There was engorgement of the retinal vessels as well as slight macular edema associated with a relative scotoma. No papilledema was present.

On February 6, 1950, the common and external carotid arteries were clamped for forty-five minutes with no neurologic signs developing. These vessels were then tied with braided silk over fascia lata. On the third postoperative day the intraocular tension in the right eye was 14 mm. and in the left eye 17 mm. On February 11th, the fifth postoperative day, there was a marked increase in the venous engorgement of the right fundus and macular edema was developing. The intra-ocular tension in the right eye was 12 mm. Ocular rotation was markedly improved. The exophthalmos of the right eye was 2 mm. On March 9, 1950, the patient said that he still had a slight noise in his head when he lay on his right side. When examined on June 15, 1950, the patient stated that since operation he had had one spell of numbness of the left side of his body which lasted about three minutes. He almost fell during the attack because he had no control of the left side. Persons who saw him thought that he was intoxicated. He also volunteered the information that he occasionally had slight numbness in the fingers of the left hand but these attacks of numbness were very transitory. The blood pressure was 135/80. Neurologic examination revealed no abnormalities. Visual acuity in the right eye was 20/30 and in the left eye 20/20. Ocular tension in the right eye was 15 mm. and in the left eye 20 mm. (Schiötz). There was 6 mm. exophthalmos of the right eye. No audible bruit could be heard. Fundoscopic examination showed moderate tortuosity and engorgement of the veins. There was still some edema in the macular region. There were many capillary aneurysms and occasionally a deep punctate hemorrhage. Visual field examination was normal.

TREATMENT OF PATIENTS WITH CAROTID-CAVERNOUS SINUS COMMUNICATION

Spontaneous cures have been reported. Sugar and Meyer[11] stated that in their collected series there was a percentage of 2.4 per cent spontaneous cures. Singleton[10] stated that spontaneous cures occur in 6 to 10 per cent of cases. In most instances, surgical treatment is the method of choice and, if possible, should be carried out before permanent, irreversible damage occurs to the eye. Compression of the common carotid on the affected side should precede any surgery, not only to determine upon which side the ligation should be performed but also to determine whether the anastomotic circulation will supply enough blood to the brain on the side of the ligation. All of our patients were subjected to digital carotid compression for five

to ten minutes and developed no signs of cerebral anemia. We thought it was unnecessary to carry out preoperative carotid compression for more than five to ten minutes for two reasons. First, all of our patients were young; and second, we operate under local anesthesia and compress the artery for thirty to forty-five minutes before finally ligating. We agree with Locke[7] that repeated daily compression over too long a period, particularly in a young person, might increase the anastomotic circulation to the point where subsequent ligation would not stop the bruit. If the patient does not tolerate carotid compression, one of two procedures can be undertaken. Some are of the opinion that by a gradual daily increase in the length of time the carotid is compressed the anastomotic circulation can be increased to the point where the patient will tolerate ligation of the carotid. Another solution to the problem when complete carotid compression produces cerebral anemia is a partial ligation; and at a subsequent date after the anastomotic circulation has increased a total ligation may then be performed.

The question of which carotid artery or arteries in the neck should be ligated has been the subject of much discussion. Sugar and Meyer[11] stated that in their series ligation of the common carotid artery alone was done in thirty-four cases. Seventeen patients (50 per cent) were cured. Internal carotid artery ligation alone was done in thirty cases. Fifteen patients (50 per cent) were cured. Therefore, it was the opinion of those authors that ligating the common carotid as compared to ligating the internal carotid showed no advantage of one procedure over the other.

Dorrance,[6] as well as others, has shown that after ligation of the common carotid alone the internal carotid artery is still fed by a reversal of the blood flow in the external carotid artery, the reversal resulting from anastomosis of: (1) the inferior with the superior thyroid, (2) the deep cervical branch of the costocervical trunk with the descending branches of the occipital and (3) the superior thyroid, lingual, facial, occipital and temporal with the corresponding arteries of the other side. Furthermore, according to Dorrance[6] approximately half of the recurrent flow into the internal carotid artery comes from the superior thyroid. He thought that this reversal of flow from the external carotid into the internal carotid should be maintained to prevent cerebral anemia. Therefore, it was his opinion that common carotid artery ligation should first be done; then if necessary, the superior thyroid and occipital arteries could be ligated. Finally, the external trunk itself should be ligated if necessary. Dorrance[6] further stated that ligation of the common carotid, rather than the internal carotid, was advantageous because of the carotid sinus. When the internal carotid is ligated, dilatation of the carotid sinus produces a fall in blood pressure which adds to the danger of cerebral anemia. When the common carotid is ligated below the bifurcation, the carotid sinus is not dilated.

Both Dandy[2] and Adson[1] pointed out that internal carotid ligation in the neck may not affect a cure. Therefore, in addition to the ligation in the neck, Dandy[2] advocated clipping the internal carotid as it emerges from the cavernous sinus; and Adson[1] not only clipped the internal carotid artery but the ophthalmic artery as well. Both state that their procedures did not impair the vision on the side of operation.

In his review Locke[7] reported twenty-one cases of bilateral ligation of the common carotid. There were three fatalities (14.28 per cent). Numerous surgeons have attacked the problem by ligating or extirpating the ophthalmic veins or by injecting sclerosing solutions into the veins. We have had no experience with this type of surgical approach, but it would seem that this should be reserved until after the attack on the arterial side has been tried.

The factor which makes it difficult to lay down a hard and fast rule regarding the procedure of choice is that the vascular patterns are so variable and unpredictable. If there is abundant circulation through the circle of Willis to provide an adequate blood supply to the brain on the side of the carotid ligation, the more completely one shuts off the flow of blood through the internal carotid artery by ligating not only the common but also the external carotid artery, the better the prognosis for patients with carotid-cavernous sinus communication.

In our own series the first patient had a ligation of the internal carotid artery only. Five years and four months later results remain excellent with no untoward effects from the ligation. The four other patients had ligations of the common and external carotid arteries. Three of the four have described transient episodes of numbness on the opposite side of the body and one of the four has had transient and

infrequent spells of aphasia. This must mean that, at times at least, there is a cerebral anemia on the side of the ligation although neurologic examination reveals no evidence of impaired cerebral function whatsoever. If in the future no more serious complication results, there is no need to regret the ligation of the external carotid along with the common carotid. However, one wonders whether in the future cerebral degeneration or convulsive seizures might result. So far as the affected eye is concerned, the results in our five cases have been sufficiently satisfactory so that no further surgery, such as intracranial clipping of the internal carotid artery, is necessary.

It seems logical to us that these patients should be operated upon under local anesthesia and a rubber-shod clamp applied to the common carotid artery. If the patient tolerates this well and if his bruit is subjectively and objectively stopped, ligation of the common carotid artery alone should be done. On the other hand, if the bruit persists and ligation of the external carotid is also required to stop the bruit, this should be carried out at the first operation. If the bruit is temporarily stopped but recurs some weeks or months following ligation of the common carotid, a second operation can be done at which time the external carotid can be tied. Further procedures, such as intracranial clipping of the internal carotid, are reserved for those cases for which the procedure seems necessary.

POSTOPERATIVE EYE FINDINGS

In the last four of our five patients, the eye findings have been carefully observed both before operation and subsequent to surgery. In these four the ocular tension in the eye of the affected side was elevated as compared to the tension in the opposite eye. In one patient (Case II) the ocular tension averaged 30 to 34 mm. of mercury (Schiötz) as compared to 18 mm. in the opposite eye and symptoms of subacute glaucoma were present. Venous engorgement and diminution in venous pulsations were present due to increased pressure in the retinal veins.

In all of these four patients the common carotid arteries as well as the external carotid arteries were tied. In each of these patients there was a striking decrease in ocular tension following operation. It would seem that ocular hypotension is a constant occurrence after ligation of the common and external carotid arteries, and this hypotension may persist for several weeks after surgery. Whether this hypotension would have been as marked had only the common carotid and not the common and external carotid arteries been tied is questionable. In each of the four patients there was no disturbance of visual acuity for the first few days after operation, but in three of the four a noticeable blurring of vision occurred on the third to seventh day following operation. Visual acuity was reduced in one case to as low as 20/200 in the affected eye. The ocular hypotension and the reduction in vision was associated with fundus changes. This retinopathy was rather striking and consisted of edema of the retina in the posterior pole associated with multiple cotton-wool patches, some cyanosis of the retina and diminished pulsation in the retinal vessels. Over a period of months there was gradual clearing of the fundus in these three patients with return of visual acuity to approximately normal. Three months postoperatively the only residual fundus finding was the presence of fine capillary aneurysms around the posterior pole in two patients, but in the third patient (Case V) there is still marked venous engorgement, a few cotton-wool patches, retinal edema, hypotony and blurred vision. This patient is also developing some subcapsular lens opacities.

SUMMARY AND CONCLUSIONS

We have presented five patients with internal carotid-cavernous sinus communications following trauma to the head. These patients have been followed from four months to five years and four months. So far, the results of ligation of the carotid artery or arteries in the neck have been sufficiently satisfactory treatment so that no other surgery is indicated.

Following ligation of the common and external carotid arteries in the neck all four patients who had this procedure developed decreased ocular tension on the side of ligation. In three of the four a striking retinopathy, characterized by edema of the retina with cotton-wool patches, ensued. This retinopathy was associated with impairment of vision which returned to normal or nearly normal in a few weeks.

Three of the four patients who had ligation of the common and external carotid arteries of the neck have mentioned that they experience transient, fleeting attacks of numbness on the

opposite side of the body and one patient has transient episodes of aphasia.

Those patients who will tolerate a carotid ligation in the neck should first have the common carotid ligated under local anesthesia. If this fails to stop the bruit, the external carotid can be ligated at the same operation. In case the common carotid ligation stops the bruit temporarily, but not permanently, a second operation can be done to ligate the external carotid. Intracranial clipping of the internal carotid and the ophthalmic artery as well as extirpation of the ophthalmic veins are procedures reserved for patients who do not respond to extracranial carotid ligations.

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DISCUSSION OF PAPERS BY DRS. JANES, BENNETT, RACK, JOHNSTON AND JORDAN, BRIEDENBACH AND LORD, AND RAAF AND SWAN

George W. Bancroft (Colorado Springs, Colo.): Dr. Janes' paper is indeed timely, covers the pathology of vascular lesion very well and his judgment and conclusions appear to be well founded.

Not one of our essayists has said a thing about exposure and to me that is primarily a question of intense interest; a key to your success is your method of exposure.

During the first World War I came in contact with two Frenchmen in Ambulance 21 by the names of Fiolle and Delmas, who were masters at exposure of the deep-seated blood vessels. I would like to describe one of their methods of gaining access to the elbow joint. We often see hematomas in the upper portion of the forearm, with a penetrating wound. Those two men made an incision on the medial side of the arm, with the arm in supernation, beginning about two fingerbreadths above the medial condyle, extending down along the biceps and over the surface fibrosis, then across the arm to the supernator longus, continuing that incision downward to a junction of the lower and median thirds of the forearm.

The fascia was incised at the same plane and beneath it one can see, after splitting the fascia, the median nerve coming beneath the pronator radii teres. If you pronate this arm at that time with traction, you can see the brachial tripod and the road is open to do what you wish to do in the cubital fossa.

Jere W. Lord, Jr. (New York, N.Y.): Dr. Janes' paper is an excellent presentation and, in the time allotted, he covered the field remarkably well.

I should like to add to his four "don'ts," another one, the "don't" of a tourniquet. I mentioned that before but I think a tourniquet should never be used unless it is absolutely necessary to stop the hemorrhage and save life. External pressure dressings will suffice in most cases. Of course, life is more valuable than the potentially evil effect of the tourniquet if it is the only way you can stop the hemorrhage.

Dr. Janes did not emphasize the desirability of restoring and maintaining the continuity as much as I believe is important. Dr. Jordan pointed that out very well. I would like to add, from what Schumacher has said and it has been true in our experience, that the more the surgeon is interested in restoring continuity or maintaining it, the greater the percentage of cases in which it is accomplished.

We had a patient who had a heavy stove fall on his leg. He was brought to the hospital within four hours. The leg of the stove pierced the anterior upper third of the femoral region of the right leg. His physician made the diagnosis of an arterial laceration and applied a pressure dressing. There was considerable hemorrhage prior to this. He gave him blood and plasma and sent him to the hospital. On exploration of the wound, instead of a laceration, a contused superficial femoral artery was found and also a contused profunda below, with no pulsation in either vessel.

We did an arteriotomy above, extracted the thrombus, closed the site of the artery and believed

that all was well. Within a few minutes pulsation ceased, the thrombus recurred and then the segment was resected.* Actually, half of the wall of the artery was fractured, and that is the reason for the recurrence of the thrombosis and extension to the lumen.

What was done in this case was to ignore the profunda artery, and to take a vein graft from the superficial femoral vein, which was intact, and do an end-to-end anastomosis, reversing the graft and using the everting mattress suture which has been so well described today. Personally, I think if one practices these two methods in a dog, the everting mattress and the continuous over-and-over suture, there is a profound difference in the leakage between the methods.

I should like to take issue at this moment, although Dr. Kenneth Lewis says you get into arguments in this Society only on fractures. There are differences of opinion also in vascular surgery, and I think there is one important thing to remember. I agree with almost everything Drs. Jordan and Johnston said, but I disagree with the point that you do not need special suture material. I had a dreadful result occur from trying to suture a vein graft to an artery, with an eyed needle that would be adequate for intestinal suture. If you don't believe it, just go to the animal experimental laboratory and try suturing with an eyed needle and a folded piece of silk, as shown in one of the drawings. On the contrary, it is perfectly simple to obtain proper suture material and many companies make either straight or curved needles. They do not cost much, perhaps six dollars a box, and may not be used for some months, but there is no excuse not to have them in every operating room where traumatic arterial injuries may be seen. That holds true whether you are doing arterial surgery, trying to suture the aorta in coarctation or the Blalock operation. It is much simpler to do a suture on an atraumatic needle than to perform it with the routine fine silk and an eyed needle.

Charles G. Johnston (Detroit, Mich.): Dr. Janes has gone over the described indications and technics very well. We prefer the eversion suture by Dr. Lord, because we think it is better. There are those doing gastrointestinal work who use over-and-over sutures and they work satisfactorily. The same is true of the vascular system. However, in the over-and-over suture part is everted and a part inverted. Clotting should occur more often in cases in which intima is not approximated to intima. Furthermore, bleeding through the suture line is more likely.

With relation to the comment of Dr. Lord about the needles, we agree perfectly with him that the ideal suture is the fine swedged needle. We prefer it and we have it in our operating room. The point we are making, and we have been in this position several times, is that where we have not had swedged needles, it is surely not something one should back away from and say, "Well, my equipment is not so good; we had better sacrifice this leg because this artery is not going to function," when one can work with what one has.

I would like to ask Dr. Bennett a question, namely, whether blood volume studies have been done. We make arteriovenous fistulas, as Dr. Jordan indicated, and we follow them with blood volume studies for a very definite reason. We do not care to overload the heart over a long period of time with these fistulas. They are made primarily to prevent clotting and to get a better circulation to the foot when we are using a vein as a substitute for an artery.

In relation to Dr. Rack's paper, I would like to state that all too often in severe abdominal injuries, in which large veins are injured, packing is resorted to when careful exposure of the bleeding vessel and suture will give better results. Dr. John Hartzell of our group had a case which was quite similar to the one that Dr. Rack reported here in which the vena cava was sutured. Since that time, we have been suturing the vena cava more frequently because it is quite often injured and we do not hesitate to expose and suture it.

With reference to Dr. Lord's paper, I think that is an exceedingly important presentation. It is important primarily because it deals with simple things. It deals with the matter of the things you and I know and almost everybody else knows or ought to know, namely, the "do's" and "don't's" about arterial insufficient limbs. Too often, however, we think we must have a lot of equipment for diagnosis and evaluation when, as he has pointed out, it is simply a matter of touch. Even the matter of temperature can be well estimated with the finger.

The errors which Dr. Lord mentions are not unusual. It is a rather common business for individuals to mishandle these limbs, despite the fact that we all should know about them. It is not a matter that we do not know; it is a problem that is mishandled because basic factors are not properly considered.

Harold C. Voris (Chicago, Ill.): Dr. Raaf is to be commended for pointing out the increase in intra-ocular tension in these cases, a finding that, to me at least, was new.

* There are many aspects of the problem of occlusion of the carotid artery in the neck that could be profitably discussed. I differ with Dr. Raaf in that I usually tie the internal carotid artery alone. The internal carotid pressure studies of Sweet and his co-workers, together with clinical evidence, I think, clearly indicate that in the majority of cases the risk is not any higher and, of course, theoretically

* Dr. Lord showed slides of this patient.

the advantage is greater than that of ligation of the common carotid alone.

In Dr. Raaf's series of cases he was fortunate in not having any neurologic complications. In a large series of carotid ligations I have done for various purposes, particularly the non-fistulous saccular cranial aneurysm, neurologic complications did occur.

Dr. Raaf's method of occluding the internal or common carotid artery under local anesthesia for twenty to forty minutes before ligation is the most practical method of determining the efficacy of the collateral circulation. Aside from inadequate collateral circulation, the most common causes of neurologic complications are thrombosis of peripheral cortical vessels or emboli from mural thrombi at the site of ligation.

I should like to emphasize the method of guarding against that, because I think that it is important for those of you who may have occasion to tie the internal carotid artery. Blocking the cervical sympathetic chain with procaine on the ligated side and repeating that block at eight-hour intervals for the first seventy-two hours and the use of papaverine as a vasodilator are of value. I would like to emphasize that histamine, priscoline or etamon should not be used because the extensive vasodilatation that those drugs produce will actually lower the intra-cerebral vascular pressure.

Finally, the use of anticoagulant therapy is, I believe, of great importance in preventing these neurologic complications which, when they occur, are always distressing and often permanently disabling.

E. S. Gurdjian (Detroit, Mich.): I think there is very little to add to what Dr. Raaf and Dr. Voris have already mentioned. I might say that the tying off of the carotid is a very serious procedure, and preoperative conditioning of the circulation on that side is most important. Even under those circumstances one may find that the carotid after ligation may cause difficulties and one may have to remove the ligature. I might say that it may be important not to cut the carotid artery after ligation. Recently, we had a case in which the carotid circulation had been conditioned preparatory to attack of a large aneurysm of the left cerebrum; we found, three hours after the ligation, that the patient was paralyzed in the contralateral half of the body. She was taken to the operating room again and we removed the ligature with resultant return of function to the opposite half of the body.

As Dr. Raaf has said, the ligation of the common carotid may not be sufficient in some of these cases, and an internal carotid ligation may be necessary later. We have believed that ligation of the common carotid, which is successful in almost 75 per cent of the cases, is the procedure of choice and appears to be less dangerous than internal carotid ligation.

The other point I wish Dr. Raaf had had a little more time to discuss was the retinal findings. One should compare these findings with those of spontaneous thrombosis of the common and internal carotid arteries. They are probably very similar.

Stewart Armstrong (Boston, Mass.): I would like to add one "do" in vascular problems in which trauma has occurred which has not been brought out sufficiently. I believe that sympathetic interruption should be carried out early, either by sympathetic blocks of procaine, or by sympathectomy when spasm persists.

I also believe that in late development of the reflex dystrophy, following trauma to any extremity, either mild or major, this should be treated early. We see so many patients who arrive two years after the onset of a reflex dystrophy, and then it is too late to correct simply. They will require sympathectomy. Reflex dystrophies seen early can be blocked either once or twice with procaine, in the stellate ganglion or the lumbar ganglia, and the cycle interrupted.

Following vascular surgery in which trauma has occurred and the vessels are ligated, I believe that sympathectomy should be done; also, as mentioned in arteriovenous fistula, I think it is most important to carry out lumbar sympathectomy before ligation of an arteriovenous fistula.

Frederic W. Bancroft (New York, N.Y.): I would particularly like to discuss Drs. Briedenbach's and Lord's paper, because I believe that they have brought out simple and realistic tests, and I am only sorry that we cannot put these in the hands of the general practitioner.

I thoroughly concur with them that the use of heat is one of the bad general practices. I can remember that during my early days at the City Hospital, diabetic ulcers or diabetic gangrene were treated under a heat tent and they got steadily worse from the time they were placed in the tent. I think heat is used in an attempt to increase a metabolism which the limb cannot tolerate because of diminished circulation.

I also think that insufficient emphasis has been put on the tourniquet as a possible thrombotic factor. If we put a tourniquet for any length of time on a damaged arterial leg, thrombosis, through venostasis, is likely to occur in the vein proximal to the tourniquet; and in observing a series of cases that were amputated under refrigeration, I could see that several had died of embolism probably due to thrombosis in the femoral vein secondary to prolonged tourniquet application.

Cold, I think, is better than heat but it seems to me that it is better to keep normal body temperature. Cold will diminish metabolism and possibly help, but we run the risk of injury through superficial burns.

It seems to me that in these papers we ought to

consider, as have Dr. Janes and others, the prophylaxis of the arterial insufficient leg, and one might say that that could be done in four steps: (1) lumbar sympathetic block. (2) If that is not successful, it has been shown that in a certain number of cases, lumbar sympathectomy has accomplished the desired results. (3) If intermittent claudication is present, I believe that one should expose the femoral artery, do an arteriogram and possibly arterial stripping. Although Leriche's theory of arterial stripping has gone by the board, it still is of benefit, even after a lumbar sympathectomy. (4) If there is a definite arterial block and the arteriogram shows decent collateral circulation, the removal of the thrombosed artery relieves the arterial spasm peripheral to it and is of distinct benefit in improving the distal circulation and curing the intermittent claudication.

I have been very much interested in Dr. Johnston's work on the arteriovenous shunt and I wish that he would tell us what his results with this have been in cases of gangrene of the toes.

Richard Bennett, Jr. (Chicago, Ill.): I want to congratulate Drs. Janes, Jordan, and Lord on their understanding of the fundamentals of the circulation of the arteries and veins, as far as anatomy and physiology are concerned.

The studies of underlying principles take me back some twenty years, when Dr. Wayne Babcock and I did a deliberate end-to-end anastomosis between the common carotid and the internal jugular, with the hope of curing a large aneurysm of the aorta. That brings me back to Dr. Jordan's and Dr. Johnston's paper, where they, too, are deliberately causing an arteriovenous anastomosis.

In our experience in the series which we carried out twenty years ago, we found that there were only two end results: (1) that if the vein, which took the higher pressure, was not adequately reinforced, huge dilatation and rupture occurred or the sac had to be resected; (2) that whether it be accidentally formed or actually formed by the surgeon, the anastomosis in the long run caused heart failure and death.

Now, I would just like to ask Drs. Johnston and Jordan how long in their series of cases, these accidental or deliberate shunts can carry on without actual damage to the heart and the welfare of the patient.

I think Dr. Lord has brought out the fundamentals and underlying principles of arteries and veins in the body. I believe that the place to start with these underlying principles is with interns and residents. I believe, and would suggest, that this Association go on record and take some tangible method of bringing to the interns and residents of the country these fundamental principles.

Charles G. Johnston (Detroit, Mich.): Some two years ago, a rather excellent discussion of vascular trauma was presented before this Association by Drs. Lord and Breidenbach. At that meeting, many of you will remember, I raised the question, which was not answered, of what to do about the distal thrombosis which we see so often. One case which Dr. Jordan presented was really in answer to this, because while we had not planned on using the vein to carry the blood in cases in which we had distal thrombosis, in our experience it has been the one good reason for doing this type of procedure and our best results are in that type of case. If one can carry the patient over for a few days or a week with a terminal vessel thrombosed without getting any real gangrene, the collateral circulation will give a great deal of help afterward. It is the acute phase in which the shunt is so important. In the case with popliteal aneurysm in which we were "left up the creek without any other paddle," we thought we might try to see if the vein would carry the blood and keep this man's foot viable, which was getting worse and worse; and we were sure, if we did not do something, we would have to amputate his leg.

The patient got a remarkable result, and has no other way, except for possible collaterals that have developed, of getting blood down to his foot than through the vein, because that was the only major vessel he had which was not completely thrombosed.

In relation to Dr. Bancroft's question relative to patients with arteriosclerotic gangrene, we have, with the three-limb method, tried it on some twenty-five cases. The results have not been good. In most of these patients immediately following operation the foot gets warmer; that has been consistent. All of them tell you their leg or foot or both are warmer and they feel better about it. However, in a day or two we found that the entire matter reverted to the original status. We were plagued with thromboses in all of our patients with three-limb shunts. It was the rule and a very rare exception when it did not occur.

In patients with arteriosclerotic gangrene who could not walk, we found that the shunt, while it was working, would allow these people to walk. They could get out of bed and their exercise tolerance was increased. But very shortly when the clot came, they were back almost where they started. Many of them, however, were able to do better with their exercise tolerance, even though the vessel, we were sure, had clotted, as evidenced by arteriograms.

Working with an arteriosclerotic vessel to make a shunt is not a very easy task. It was for this reason that we started in the laboratory to see whether we could keep the clotting down; because if a clot occurs it is no good. In all the dogs in which we did

three-limb shunts clotting occurred, while those in which we did arteriovenous fistulas first and then closed the fistula afterward, stayed open. Therefore, I think we are getting around the clotting problem fairly well.

There is one other question that was asked, that is, how much dilatation we get with the veins in those that we make or that are accidentally made. We all know that at the site of the arteriovenous fistula, there is usually a large amount of dilatation. Our experience has been that the vein graph carrying arterial blood does not dilate very much in the long-term program. They dilate immediately, obviously, when the pressure is put in them, but they do not continue to get larger afterward. As a matter of fact, they tend to have some fixation and thickening and become a little smaller. In arteriovenous fistulas the problem is in relation to how long they will go before they get cardiac failure, and that depends on many circumstances, namely, how much work the man does, how active he is, the size of the fistula and how close to the heart it is.

I do not think arteriovenous shunts are a cure-all. A gangrenous foot remains dead and must be sloughed off. We have found diabetic arteriosclerosis most difficult. Arteriosclerotic disease without diabetes has given us a little but not much better response.

HOWARD E. SNYDER (Winfield, Kan.): I was particularly interested in Dr. Jordan's and Dr. Johnston's contribution. I was a little surprised at the figures quoted, from the European Theater on the incidence of gangrene or loss of an extremity with interruption of various arteries. In those figures the incidence of gangrene was greater with femoral artery interruption than with popliteal injury. In our experience the popliteal injury was always the more serious, and superficial femoral lesions did not lead to gangrene in a great percentage of cases.

I think the problem of application of this technic, which Drs. Jordan and Johnston have presented, to popliteal injuries is something that should be considered. In our experience vein grafts, using the Lord-Blakemore tubes, did not increase our good results at all. We thought perhaps it was because added operative trauma interfered further with the collateral circulation.

I should like to report briefly a technic used recently in a saddle embolus, in a seventy-three year old diabetic, who had an auricular fibrillation for fifteen years. Surgery was done fifteen hours after the embolus. An embolectomy and bilateral lumbar sympathectomy were performed. Heparinized blood was infused in the common iliac arteries distal to the operative area during the operative procedure. The blood was diluted half with saline and the heparin added; and while the vessels were occluded, this blood was given through the distal arteries. At the conclusion of the repair of the aorta the constrictions on the iliac arteries were removed first, so that the heparinized blood bathed the operative area, and then the aortic constriction was removed.

This patient, in spite of being a diabetic and a delay of fifteen hours after saddle embolism before surgery, developed good circulation in the right extremity, which had been cold and anesthetic to the knee. She did develop localized gangrene in the anterior tibial group of muscles in the left extremity, but the gangrenous area has been excised and she is about ready for skin grafting.

I cannot help but believe that the use of heparinized blood in the distal arteries during the operative procedure perhaps did prevent further thrombosis and aided in the salvaging of both lower extremities.

J. M. JANES (closing): I would like to draw attention to a fact that was brought out by Dr. Elkin of Atlanta, that when one is doing a quadruple ligation excision, it is well to ligate the proximal vein last. I do not think that was brought out. It allows drainage from the fistulous area till the completion of the operation.

I wish to thank Dr. Bancroft for his fine presentation of incisions. As we all know, adequate incision is the first step in vascular surgery.

With regard to experimental arteriovenous fistulas, we have recently adopted that method of attempting to increase the leg length of puppies, with the idea probably, if it is successful, of applying it to a child with a short leg due to anterior poliomyelitis. The procedure is creating the fistula, allowing the increased bone growth to occur and then repairing the fistula.

RICHARD J. BENNETT, JR. (closing): Mr. Chairman the case which I presented, I saw the patient for the last time on Tuesday of this week, and he returned to work one month after his quadruple ligation operation, and has not lost a day since, which just shows that this operation can be performed successfully. His complaints, however, are numbness down the anterior portion of the leg, and some deep pain on pressure.

Dr. Janes brought up the fact that the vein should be ligated last. I just want to report an observation about that. When dissecting out a tedious arteriovenous communication and one breaks into the blood stream, the tapes around artery and vein are compressed almost instantaneously to check the flow of blood without priority.

Dr. Johnston asked if blood volumes were carried out. No, they were not available in the hospital in which these procedures were done.

PRESCOTT JORDAN, JR. (closing): As far as suturing in dogs is concerned, we have used different types of suture materials and have finally

gotten down to the swedge on needle, as Dr. Johnston has said. But we did find that cotton was a perfectly adequate suture, and in the dogs, for portacaval shunts, we used a regular round needle, with No. 4-O silk run through the eye. The percentage of patency was 95 per cent in these animals, so we have not had too much difficulty, at least in dogs with non-absorbable sutures and fine needles. I have tried cutting needles and eye needles but they are not suitable.

JERE W. LORD, JR. (closing): This is probably the longest time it has ever taken a person to reply formally to a question, namely, the one that Dr. Johnston asked two years ago and which was not answered. If I understand correctly the way it was asked then: in acute arterial emergencies that are seen a little later than the ideal period of the first few hours, it may be difficult to get the distal artery free from clot. There is no question about it; that it is absolutely true. Other than irrigation and suction, I know of no special methods. We have seen that problem not in the arterial emergency group but particularly in the patients whom Dr. Bancroft asked about, those who had an acute thrombosis of a critical artery, like the popliteal artery, and who were seen eight, ten, twelve, fourteen or twenty-four hours afterward. In my experience thrombectomy under those circumstances has met with uniform failure; and I think Drs. Johnston and Jordan should, at least as far as I am aware, get the credit for bringing to the fore this method of attempting to produce a fistula in the extremities which they did in the College of Surgeons last Fall.

As Dr. Jordan pointed out, it began somewhere in the early part of the twentieth century, but it did not gain general interest until they applied it. I have had some experience with it—some seven or eight cases at Bellevue and one or two private patients—and one or two patients have shown marked improvement in a short period of follow-up after a few months. Others have shown no improvement and two have died following the procedure. The operation was an incidental event in the downhill course of a patient due to cardiac failure. It is simply a question of working out some bugs or wrinkles in the procedure which will eventually be a valuable operation.

JOHN RAAF (closing): I should like to thank Drs. Voris and Gurdjian for their excellent remarks. I agree regarding the use of sympathetic block and papaverine in conjunction with ligation of the carotid in order to increase the cerebral circulation. However, I should like to point out that anticoagulant therapy following neck surgery is not without some danger. We operated upon a child with a non-traumatic intracranial aneurysm. The internal carotid in the neck was ligated and we gave her anticoagulant therapy. She developed a hematoma in the neck wound which compressed the trachea to the point that her condition was serious before the wound was opened wide and the clot evacuated. The patient must be observed carefully for postoperative hemorrhage if anticoagulants are used.

RESULTS FROM THE TREATMENT OF SCIATICA DUE TO LUMBAR DISC PROTRUSION*

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IN the past ten years surgical operations for protruded lower lumbar intervertebral discs have become commonplace. When it is recalled that prior to the present surgical era in the treatment of sciatica due to disc protrusions, severe permanent disability was unknown, the argument for conservative non-operative treatment becomes more logical.

On the other hand, prolonged total disability of many months and varying degrees of residual back pain was experienced. Kirstein reported a follow-up study on two small groups of patients for a comparative analysis of the results of non-operative treatment versus partial disc removal. Complete and permanent recovery from symptoms was four times as frequent in the operated group (48 per cent) as compared with the non-operated group (12.5 per cent). Colonna and Friedenberg reported a similar study on twenty-eight patients who were not operated upon and on ninety-five patients subjected to partial disc excision. Seventy-one per cent of patients had residual pain in the unoperated group, as compared with only 40 per cent in the operative series. Neither group was unselected, which is also the case in the present study.

Operations for disc protrusions are not inocuous, as both vascular and neurologic complications occur complicating the conventional posterior approach. At least six grave injuries to the great vessels anterior to the vertebral bodies have been reported.[22,27] Poppen[33] and Ver Brugghen[44] have warned against the danger of producing a massive protrusion of disc substance with paraplegia by manipulative procedures. In the past ten years, the author has seen nine cases of permanent paraplegia which have followed "disc operations" performed elsewhere.

As our knowledge of a condition accumulates, it is often possible to set up rules of procedure for the treatment of specific cases selected from the group. This paper will deal with a procedure for the selection of cases for two types of operative treatment which is practiced in the Department of Orthopedic Surgery at the Permanente Hospitals. The aim is for as exact a diagnosis as possible followed by as simple a surgical procedure as possible which will yield a long term result for the patient.

REVIEW OF THE LITERATURE

No attempt will be made to present a complete summary of all the reports of the treatment of sciatica due to lower lumbar disc protrusion or even to summarize the much smaller number of papers that report results from various types of operative procedures. White and Peterson,[46] summarizing results of 900 cases of disc excision from the literature, found 67.6 per cent good or excellent results and only 15.3 per cent unimproved. Odell and Key,[30] in enumerating results from operative attack upon lumbar discs alone without fusion, state that various authors[11,20,26,28,33,42] have reported excellent results in from 50 to 95 per cent of patients who have been operated upon. The lower percentages were observed in patients in whom Workmens' Compensation or other insurance was involved. Aitken and Bradford,[1] in a study of the experience of a large insurance carrier, found only 38.2 per cent good results in 115 cases in which disc protrusions were found at operation and only 15 per cent good results in seventy-three cases where operation resulted in negative findings for protruded discs. Schumate[34] reported 52 per cent good and excellent results from disc operations in 200 industrial insurance cases. Parrella and Zovickion[31] observed 78 per cent good and excellent results in a Veterans' Hospital.

Farrell and MacCracken[16] found the same incidence of pain relief in persons suffering from sciatica associated with lumbosacral instability regardless of the fusion being combined with exploration for intervertebral discs. A. T. Moore[29]

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obtained good results from spinal fusion for sciatica due to spinal instability although the majority of his patients did not have disc protrusions (ten of fourteen cases, 71.4 per cent) as determined by exploration.

per cent unsatisfactory results from conservative treatment among fifty-five patients. Obviously, only a fraction of cases from these latter groups represented persons with disc protrusions.

TABLE 1

EFFECTS OF VARIOUS TYPES OF SURGICAL TREATMENT FOR PROTRUDED DISCS

	No. of Cases	Myelography			Follow-up Data				Percentage not Relieved with Workmens' Compensation Status
		No. of Cases	Positive		Time (Mo.)		Per cent Relief from Sciatica	Per cent Relief from Back Pain	
			No.	Per cent	Median	Minimum			
Posterior disc removal without fusion; chiefly extraction of sequestrated fragments	36	16	13	81.3	24	12	97.2	63.9	92.3
Posterior fragmentary disc removal with fusion	24	15	12	80.0	36	12	100	66.6	75
Posterior fusion without disc removal	30	13	7	53.8	14	8	90	86.6	50
Anterior disc removal without posterior fusion	20	20	20	100	18	12	100	85.0	33
Anterior disc removal with posterior fusion	10	9	9	100	12	8	100	100	0

There is lack of agreement as to the advisability of fusion of the spine at the time of removal of disc remnants. Most orthopedic surgeons, recognizing that the spinal segments effected by degeneration of the intervertebral disc are also unstable, prefer simultaneous fusion. Ghormley et al.,[18] Smith et al.,[37] Barr,[2] Steindler[41] and Crawford et al.[12] have demonstrated superior results in cases that have also been fused in addition to having an operation upon the intervertebral disc. On the other hand, Caldwell and Sheppard[7] considered that fusion would not have improved their results which were considered as "excellent and satisfactory in a high percentage (82.7) of cases." Waris[45] reported that 66 per cent of 374 patients had continuing low back pain following removal of herniated lumbar discs.

Finally, the results from the non-operative treatment of patients with sciatic radiation of pain should be considered, although it should be recognized that these probably do not include all of the severest cases. Kuhns[24] reported 79.5 per cent relief in 449 cases with sciatic radiation of pain treated by conservative non-operative measures. Dunning[13] found only 46

This report is based upon a study of the records in 1,500 cases admitted to the hospital during the past eight years and personal experience with 580 of the total group. Conservative treatment, consisting chiefly of traction-suspension or Buck's traction applied to both lower extremities, bed rest on a firm mattress and a variable program of heat, massage and active exercises, was applied during the first five years of this period. The cases of intractable pain or those that did not respond after a two to six weeks' regimen of the above type of treatment were subjected to exploration with removal of disc protrusions and degenerated portions of the disc during the same period. The detailed statistics of this latter group will be mentioned only to point out that they were inferior to those achieved when the operative procedure was combined with fusion of the lower spine as was practiced during the past three years. (Table 1.)

The following regimen has been in practice during the past thirty months. Every patient is at first given a variable amount of conservative treatment consisting of Buck's extension to both lower extremities, bed rest on a firm mat-

tress, regular periodic sedation with empirin, and occasionally with narcotics for a few days, and physical therapeutic measures consisting of infra-red and massage. Some patients receive injections of curare, some are subjected to leg and back manipulations under anesthesia, and many patients receive some type of back support, usually a rigid duraluminum and leather chair-type brace. Patients who have roentgen or physical evidence of instability at the lumbosacral junction, including those who have a recurrence of sciatic radiation of pain after they become ambulatory and who again receive amelioration of their pain by bed rest or who have a history of habitual relief by recumbency, are subjected to spinal fusions of the fourth and fifth lumbar vertebrae to the sacrum without exploration for disc protrusion and without myelography, unless the latter has been done on some other indication. The patients who have intractable sciatica not responding to any of the conservative measures described or who have severe recurrences of sciatica over a period of several months or several years are subjected to spinal myelography including chemical study of the spinal fluid and its dynamics. It is believed that a positive diagnosis, including the presence of intradural tumors, can be made upon the basis of the combined clinical picture and myelograms in a very high percentage of cases. If protruded disc is diagnosed, the patient is subjected to subtotal excision of one or both of the lower two lumbar intervertebral discs by an anterior transabdominal extraperitoneal approach through a left lower pararectus incision. This operation is an evolutionary modification of the transabdominal operation previously described by Lane and Moore.[25] The anterior annulus is opened by a trap door incision, the hinge of which is on the right side. The physical properties of a normal or a degenerated disc are easy to distinguish under direct vision, the latter being dry, sequestrated to a varying degree and easy to remove. The space formerly occupied by the intervertebral disc after being carefully cleared and denuded of annulus fibers, except at the periphery, is filled with cortical bone grafts cut to size, and a small plug of cancellous bone is used to obliterate the remaining anterior portions of the disc space. The detailed operative technic will not be described here, as this has already been done elsewhere.

The posterior fusions are chip fusions performed according to the Henry-Briggs technic. In addition, vitallium® screws are used for transfixion of the articular facet joints. In about two-thirds of the cases osseous chips were prepared from bank bone, chiefly ribs preserved in merthiolate solution.

RESULTS

The first operation of this series of thirty subtotal anterior excisions of the lumbar intervertebral discs was performed April 13, 1948, and the last to be considered here was done in October, 1949. There was no mortality and only negligible morbidity. During this eighteen-month period the thirty cases of disc excision and anterior fusion represented 11 per cent of all the cases complaining of low back pain accompanied by evidence of irritation of the fifth lumbar and/or first sacral nerve root which were treated in the hospital during the same period of time.

During this period the following disposition was made of similar patients treated in the hospital: conservative treatment, 206 cases (80 per cent); removal of intervertebral disc remnants and fusion by the posterior route, four cases (1 per cent) and posterior spinal fusion alone, twenty-four cases (8 per cent). The following variations of operative procedure were carried out on the thirty patients: two discs excised (usually the fourth and fifth lumbar discs), twenty-three cases; one disc excised (the fourth or the fifth lumbar disc), seven cases and posterior fusion with bone chips and facet screws was combined in ten cases with anterior disc excision.

The reasons for removing only one disc are rationalized as follows: (1) inability to enter the fifth lumbar space due to subligamentous ossification, three cases; (2) technical difficulty with the surgical approach to the fourth lumbar disc, one case; (3) technical difficulty with approach to the fifth lumbar disc, one case and (4) election to remove the fifth lumbar disc only, two cases.

Following the operations surgical shock did not occur. Postoperative blood transfusion was carried out in only three of the thirty cases, all instances in which posterior fusion had been combined at the same time with anterior disc exploration and removal. With three exceptions, when the patients regained consciousness following operation, they stated that the nerve root symptoms which they had prior to the operation were gone. Paresthesias disappeared in

1A 1B 1C

FIG. 1. Fourth and fifth lumbar discs excised for degenerated and protruded fourth lumbar disc. Fourth lumbar disc protrusion was demonstrated by pantopaque myelography and confirmed at anterior operation. Autogenous cortical tibial grafts used for intercorporal replacement; no posterior operation. Immediate and lasting relief from low back pain and sciatica with return to work in three months as a mechanic. Total period of postoperative observation twenty months. Bending films in the lateral projection show vertebral body fusion after four months. A, lateral preoperative roentgenogram demonstrating narrowing of both fourth and fifth lumbar interspaces; B, postoperative roentgenogram after six weeks; C, postoperative roentgenogram after fourteen months. The cortical bone grafts are still not completely substituted by living bone and are still more dense in the center than at the periphery of the grafts. However, osseous union is present between grafts and the neighboring cortical plates of the vertebrae.

a few days in two cases and more slowly in the remaining case.

Each patient had previously been fitted with a chair-type back brace and was allowed out of bed in a wheel chair or ambulatory on either the second or the third postoperative day. The average number of postoperative days in the hospital was 20.7. The extreme number of postoperative days was nine and sixty-five. Only three patients spent more than twenty days in the hospital.

Following discharge from the hospital each patient was seen at least every month and some more frequently. On each visit the patients were examined with special attention to the following points: (1) relief from back and leg pain; (2) intactness of the abdominal wall; (3) reflexes and sensation of the lower extremities; (4) auscultation of the abdomen and (5) making of rotengenograms of the lower back. Beginning three months following operation and at one or two monthly intervals up to one year, flexion-extension roentgenograms were made in the lateral projection. In the twenty cases uncomplicated by posterior fusion, immobilization of the spine by the anterior fusion was observed between three and six months. There was no evidence of postoperative herniation in any patient and no evidence of arteriovenous fistulas which has been reported as an accident following posterior disc operations. In one instance the patient complained of increase in temperature of the left lower extremity and this was verified by palpation and with a thermocouple. This persisted for about two months and was thought to be due to contusion of the left lumbar sympathetic chain. The only other morbidity observed was the following: (1) cotton stitch extrusion, two cases; (2) neuritis of the lateral femoral cutaneous nerve on the side opposite the original nerve root paresthesias. This was produced by scar tissue formation around the anterior superior spine in an instance in which the site of removal of an iliac bone graft was too far anterior, one case; (3) contusion to the left lumbar sympathetic chain (previously

2A 2B 2C

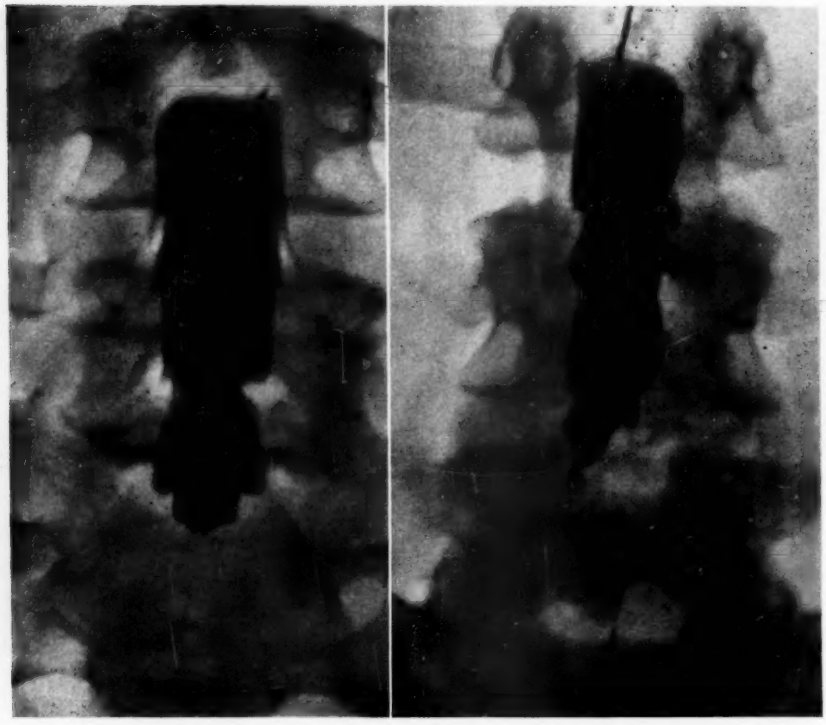
FIG. 2. Fourth and fifth lumbar discs excised for degenerative disc disease of both spaces. Protrusion was present in myelograms only at the fourth interspace. Homogenous refrigerated grafts used to obliterate the intercorporal spaces and for simultaneous posterior fusion. Facet screws were practical only at the lumbosacral joints. Immediate and lasting relief from low back pain and sciatica. The patient, a housewife, engaged in full activities at four months; total period of postoperative observation seventeen months. A, immediate postoperative roentgenogram in the lateral projection; B, postoperative roentgenogram at five and one-half months. Osseous union was demonstrated by lack of motion in bending films made a month prior to this roentgenogram; C, postoperative roentgenogram at ten months showing complete osseous fusion of vertebral bodies from the fourth lumbar to the first sacral.

described), one case and (4) hysteria with weakness of both lower extremities occurring three months after operation and rapidly yielding to psychotherapy, one case.

It is of interest to note technical difficulties and other observations made at operation: In five cases, the exposure of the anterior annulus was somewhat difficult because of variability in placement of the greater vessels relative to the vertebral structures; a posterior disc pocket was visualized seven times; anterior disc protrusions were observed three times; extreme degeneration of annulus fibers and consequent ease of removal of the disc material was observed in every case in which a rounded myelographic defect was observed at one or more intervertebral spaces, even in the same individual. The ease of subtotal removal of a degenerated intervertebral disc in which there was variable sequestration of annulus fibers is quite definite and is in marked contrast to a normal disc, the removal of which is more difficult because of the adherence of annulus fibers to the cortical osseous plate and to one another. Three patients (10 per cent) had previously had protruded disc fragments removed by the posterior route without fusion two to six years before. In two of the three cases the disc contents of the space previously operated upon appeared normal.

In the cases in which disc removal alone was carried out without posterior fusion, seven of twenty cases (35 per cent) demonstrated a variable amount of back pain during the first three postoperative months. In most of these cases the patients had minor symptoms, except for occasional acute exacerbations of pain lasting one to three days. The exacerbations were severe enough to require hospitalization and recumbency in two cases, but in only three cases did the pain persist more than three months. The persistent back pain accompanied by exacerbation was thought to be due to settling at the facet joints and/or associated with change of support of the vertebral bodies in the anterior region.

The end results from the operations eight to twenty-six months later (Figs. 1 and 2) can be listed as follows: (1) return to previous work, twenty-seven cases (90 per cent); (2) delayed



3A 3B

FIG. 3. A and B, myelograms made with pantopaque in two patients treated satisfactorily by posterior spinal fusion without exploration for protruded intervertebral discs. Typical defects are shown in each case.

return to work (eight to eighteen months postoperatively), six cases (20 per cent); (3) immediate relief of paresthesias from nerve root irritation, twenty-seven cases (90 per cent); (4) slower relief from paresthesias, three cases (10 per cent); one case required nine months; (5) persistent complaint of low back pain longer than three months, three cases (10 per cent). Two of the three latter patients were more than fifty years of age, and the third was a Workmens' Compensation case who obtained a "final settlement" two years after operation and then disappeared from observation.

Thirty patients have been subjected to posterior spinal fusion of the fourth and fifth lumbar vertebrae to the sacrum during the past thirty months upon the indication of relief of nerve root irritation by recumbency. Relief, to be acceptable, must be subjectively complete and accompanied by appreciable or complete disappearance of hamstring spasm as tested by straight leg-raising. Myelography with pantopaque was performed on only thirteen cases (43.3 per cent) in the group selected for operation by spinal fusion alone. Of these, only seven (or 23.3 per cent of the entire group) showed typical alterations in myelograms. Assuming that myelography will visualize 80 per cent of protruded discs, it can be concluded that at least 30 per cent of this entire group had disc protrusions comparable to patients on whom other types of operations were done. (Fig. 3.) It can also be assumed that the lack of persistence of paresthesias which allowed selection of this group of cases denoted less severe or perhaps intermittency of disc protrusions.

The incidence of relief from nerve root irritation following spinal fusion alone in the selected group was similar (Table 1) to that obtained by direct operative attack upon the disc or disc protrusions by either route, as this table has no statistical significance. Only one case demonstrated continuation of nerve root symptoms of such a degree as to warrant subsequent operative attack upon the disc.

COMMENTS

The incidence of surgical attack of all types in the entire group of 1,500 cases has been only 10.3 per cent, including thirty-five additional patients who were operated upon and who were not included in the follow-up data of Table 1

for one of the following reasons: the patients could not be located, the progress notes in the chart failed to cover a period of less than twelve months or the patients had been operated upon less than eight months prior to this report. The long-term necessity for surgical treatment for persistent sciatica due to lumbar disc protrusion cannot be considered to be this low because of the lack of adequate follow-up on about a third of the patients to whom conservative treatment alone was applied. Doubtless if cases responding to surgical treatment on a single hospital admission were all followed for a period of several years, the requirement for surgical treatment due to recurrence of symptoms would be considerably greater.

The true incidence of degenerative lumbar disc disease with disc protrusion in the group treated conservatively is unknown, as it has been our policy to perform myelography only in certain, but not all, cases in which symptoms are sufficiently prolonged to warrant consideration of surgical attack on the intervertebral disc. A myelographic defect when demonstrated was considered only one of several factors upon which the final decision was made. As a result, patients with low back pain alone due to disc protrusion with mild symptoms are never subjected to myelography.

Direct visualization of the interior of the disc space from the anterior aspect and the difficulties encountered in removing sufficient of the contents to constitute subtotal excision, even under these circumstances, will convince any surgeon that even the most thorough curettage of the disc space from a posterior interlaminal approach will effect removal of only a small percentage of the total intercorporal contents. This has also been demonstrated by the cadaver experiments of Falconer et al.[14] It follows that if it is the surgeon's intention to remove as much of a degenerated disc as possible, this can be done only through the superior exposure of an anterior approach. An adequate extraperitoneal exposure requires a certain degree of anatomic knowledge and technical skill and is recommended only for the experienced surgeon. Under these circumstances a host of theoretic objections to the anterior approach have not been borne out by practical experience. It should be pointed out, however, that the anterior approach for removal of the contents of a degenerated lumbar disc is purely a therapeutic operation to be applied only when the surgeon is positive of the diagnosis. Once the operation is undertaken it cannot be modified upon the basis of the findings.

While the author first applied the anterior approach hesitantly to three cases of intractable recurrent sciatica previously operated upon by the posterior route, it is now regarded as an elective operation for any type of lower lumbar intervertebral disc protrusion except cases in which the diagnosis is not clear or in which the operator suspects massive or complete disc fragment extrusion into the extradural space. The posterior approach is employed under these circumstances.

Since most disc protrusions are not complete extrusions of large fragments of annulus and a high percentage have only thinned and have not completely broken through the peripheral annulus, the anterior approach will deal with the majority of cases with complete satisfaction. In the author's experience a posterior disc pocket or posterior annulus defect has been clearly demonstrated in only half the patients operated upon by the posterior route. On the other hand, an adequate appreciation of the degree of degeneration of the entire intervertebral disc can be obtained only by the anterior exposure.

No discussion will be undertaken on the merits of posterior fusion as combined with operations on the intervertebral disc by the posterior route, as this point is without the scope of this paper. While there is no agreement on this point, it is considered by many orthopedic surgeons, including this author, that the spinal instability associated with degenerative disc disease sufficiently severe to produce intractable and recurrent sciatica requires fusion of the spinal segments involved. While this opinion may not be backed by the summary of Table 1, the severity and persistence of the low back complaints of many patients following removal of disc fragments exceeded those on whom fusion was performed. Low back complaints in the patients following fusion were mild and infrequent except in certain patients with a Workmens' Compensation status.

It is this author's opinion that good results in the surgical treatment of degenerative disc disease of the lower lumbar spine are secured only by careful selection of cases for operation. Operation is not indicated solely by a myelographic defect, but the decision for surgery is based chiefly on the degree of incapacity of the

patient and his failure to secure adequate relief from perhaps several well supervised courses of non-operative treatment. In this respect a myelographic defect is considered as a diagnostic and localizing sign to be interpreted for each individual rather than a surgical mandate. Dural indentation by the protruded degenerative disc is seldom a progressive defect and not at all comparable to a defect caused by a neoplasm. Careful selection of patients for operation also implies consideration of the age and careful evaluation of the amount of degenerative hypertrophic arthritis present in the lumbar and lumbosacral spine. In selected series few patients will be found below twenty years of age or above fifty. These age limits and the presence of arthritic change are relative as are all other indications for operation in degenerative disc disease, including sensory and reflex changes in the absence of muscle weakness. In general, suitable cases for operation exhibit several indications.

SUMMARY AND CONCLUSIONS

1. A follow-up study for median periods of twelve to thirty-six months on 120 cases of severely persistent and recurrent sciatica due to degenerative disc disease of the lower two lumbar intervertebral discs, treated by a variety of surgical methods is reported.

2. Surgical treatment was required in 155 cases (10.3 per cent) of 1,500 cases of sciatica with and without low back pain admitted to the hospital during an eight-year period.

3. All surgical methods considered in this study were quite effective in relieving the radiating pain due to nerve root irritation, but the incidence of relief from low back pain in the same patients was not as high.

4. Failure of relief from low back pain was commonly encountered in patients treated by surgical methods who also had Workmens' Compensation status.

5. Complete relief from sciatica was obtained in all thirty patients in whom subtotal excision of one or both of the two lowest lumbar intervertebral discs was carried out by an anterior transabdominal extraperitoneal approach. Relief from low back pain was observed in 90 per cent of the same patients. Various observations on this group of patients are described, indicating that in experienced hands, this operation can be employed for therapy when the diagnosis has been definitely made.

6. Posterior spinal fusion of the fourth and fifth lumbar segments to the sacrum also gives relief from both sciatica and low back pain in patients with these complaints who have suffered repeated and recurrent attacks over a number of years but who are relieved temporarily by recumbency prior to operation. Fifty-three per cent of thirteen patients in this group had disc protrusions demonstrated by myelography. The patients differed only in the criterion of relief from recumbency from similar patients on whom direct surgical attack upon the degenerated discs was carried out because of failure of relief from non-operative methods of treatment.

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DISCUSSION

Kellogg Speed (Chicago, Ill.): From a technical standpoint, I have been interested in this subject because some years ago I reported a method of anterior approach to fuse the lumbosacral joint in cases of spondylolisthesis in which the fifth lumbar has slipped forward on to the sacrum. In those cases I made a transperitoneal approach by midline laparotomy. One has simply to tip the patient back, pack off the intestine and expose the branching of the aorta into the main iliac arteries. About the only structure you may injure in that method would be the mid-sacral nerve plexus.

Dr. Harmon has written a very fine paper on a controversial subject. He did not have time, of course, to give you everything that is in his paper. His discussion includes not only a review of the recent articles on this topic, which is a labor in itself, but also a statistical compilation of his own experiences. For these, we are indebted to him, but it is very difficult to take a basic interest in

statistics in any medical subject, especially such as this, in which so many of the complaints are subjective, very little of the pathogenesis involved reaches the eye and not much more of it reaches the imagination.

It seems to me that it is difficult to state whether we are dealing with, (1) degenerated discs, (2) extruded discs otherwise normal or, (3) traumatized discs involving tears and ruptures of the annulus fibrosus with resulting hemorrhage and local conditions somewhat resembling a sprained joint with possible addition of local pressure effects on posterior nerve roots and other nervous elements. May we not in some instances have a combination of these factors?

One thing I find almost impossible to state is just what causes the pain. May it be mechanical from abnormal pressure on vertebral facets from tilting of the bodies and easily recognized scoliosis and rotation of the spine, or may it be definite severe sciatic referred pain from nerve root pressure or irritation? Many pains from these causes yield to immobilization by external splints and supports on the back, which bring symptomatic relief to a large percentage of the individuals thus affected. Also, if support is continued long enough, a quite permanent cure often ensues, leading one to wonder just what the pathogenesis really was. Some backs are not freed from pain by well performed bony fusions, although at first the cure may seem to be in hand before renewed activity.

Consequently, we need an easier diagnosis, better roentgenographic examination, to put factors in our hand which may lead to an easier grasp of the nature and severity of the individual case.

Fusion, by aid of small bone chips implanted after anterior extraperitoneal approach, may lead to cure, especially in instances of degenerated disc. But if two or more discs are degenerated and this is not found or recognized by the surgeon, recurring difficulties are bound to follow later, when the statics of the spine are interfered with by local fusion of one or two levels but not including all diseased areas.

It seems to me that Dandy was overconfident in his diagnoses and overindulgent in operating upon such a high percentage of his patients after what to my slowly moving mind, in back examination, seemed a snap diagnosis. I believe also that both Mixter and Love have modified their quite radical viewpoints in diagnosis as early exposed.

We require better, deeper study of the spine, its anatomy, blood supply, reactions to trauma, and aging processes, its mild inflammations and arthritides. Schmorl's work in Dresden was a magnificent start, and years of additional work, coupling the laboratory with the operating room, must be pursued before a ready-at-hand, relatively sure method of diagnosis and better treatment can be placed in the surgeon's hands. Dr. Harmon's excellent report and study fits into this scheme.

E. S. Gurdjian (Detroit, Mich.): I have not read Dr. Harmon's paper but one has to keep in mind that cases of low back pain may be divided into three classes neurologically: those who have no neurologic deficit whatever, those who have minor neurological deficit, such as paresthesias, slight numbness and loss of reflexes and, finally, those with severe neurologic deficit, such as a foot drop, varying degrees of paraplegia and sphincter paralysis. A great deal of what you should do depends upon the type of the neurologic condition of the patient.

In many instances, with severe sciatica, there may be a rupture of the intervertebral disc through a torn annulus, with a piece of the protruded material actually tucked in the intervertebral foramen. In cases in which recurrences of pain or no improvement following operation are noted, it is quite likely that this tucked-in piece of tissue in the intervertebral foramen was not removed. In cases with root pain it is certainly mandatory to explore by the posterior approach and ensure exploration of the outgoing nerve and its surrounding tissues. The anterior approach cannot take care of some of these cases adequately.

The question of myelography is rather important. Dr. Dandy pointed out that in a patient with low back pain with sciatic radiation, exploration of the fourth and fifth lumbar interspaces on the affected side may be sufficient. In many instances that is quite all right; on the other hand, by a more careful study one finds, on myelography, that some patients have cord tumors, others have large varicosities about outgoing nerves, and still others have lesions elsewhere than at the fourth and fifth interspaces. Myelography at the level of the fifth lumbar interspace may reveal false negatives, but at higher levels, myelographic evaluation is much more accurate.

As Dr. Speed has said, and I am sure as Dr. Harmon has discussed it in his paper, this is a rather large subject and there are many problems to be analyzed. The approach to this subject by different methods, by various groups, is the best one, and certainly, in the course of another ten or twelve years, a plan will evolve which is probably the best method of managing these cases.

Harold C. Voris (Chicago, Ill.): I enjoyed very much the opportunity of reading Dr. Harmon's paper, and I am prepared to agree that a more complete excision of the disc can be done by the anterior route than by the posterior approach. I take it that Dr. Harmon believes that the thorough excision of all disc material possible is essential to successful surgical treatment of these patients. I am not convinced of that point, and am inclined to believe that the removal of relatively

loose and fragmented disc material is all that is necessary.

To me, neurosurgically oriented, of course, the decompression of the nerve root, with removal of any small pieces of extruded disc material is essential. Because of their small size, these are often difficult to visualize at operation let alone recognize by the amount of defect in the myelogram on which Dr. Harmon depends. The decompression of nerve roots seems to me to be a more important factor in the cure of a patient's root pain than thorough removal of all possible disc material.

There is only one other point I want to mention. In Dr. Harmon's paper, he refers to the danger in the posterior approach of going through the anterior longitudinal spinal ligament and injuring the great vessels. That complication has been reported. I was shocked when I heard that it could occur, and I have never gotten over that shock. I want to close my discussion by pointing out that if a surgeon using the anterior route should be so unfamiliar with the limitations of the disc space and so unable to control himself that he got beyond the confines of disc space, he could likewise do serious damage to the contents of the spinal canal. That damage would not be apparent at the moment it was done, but it would certainly be apparent as soon as the patient regained consciousness.

Dr. Harmon is to be congratulated upon his use of this relatively new technical procedure, and it is through continued controversy and exchange of opinion and experience on this subject that we may eventually achieve standardization on what is, of course, an extremely important matter.

Edgar L. Gilcreest (San Francisco, Calif.): I think we would all be interested to know how many of these patients Dr. Harmon had were industrial patients and how many were private, and what per cent of cures he got in each of these two series. I think we all know that we get a much better chance of amelioration of symptoms and a possible cure in the private patient than in the industrial patient.

I should also like to ask Dr. Harmon from where he thinks the pain emanates. Does he think it is just a protrusion of the disc on the nerve, or does he think you get other conditions around the facets of these joints that set up these aches?

I think anyone operating upon these patients must restrain himself so that he does not get too enthusiastic in the various operative measures, as my former classmate, Walter Dandy of Baltimore did. He spent just a few moments in taking the patient's history, whether that patient was a doctor or a layman and he would operate the next day. Walter did so many of them that I think there are few of us who have not seen some of his former patients who still have symptoms. As I said, we should not become overenthusiastic in these operative procedures.

Ruth Jackson (Dallas, Tex.): We often forget the mechanics involved. A ruptured disc is a little more than just a ruptured disc, inasmuch as the nucleus pulposus is ruptured. The nucleus pulposus acts as a hydrodynamic ball bearing between the vertebrae, and it also keeps the vertebrae apart. Once the nucleus pulposus is ruptured from whatever cause, whether it is degeneration or trauma, there is a mechanical alteration or derangement. The weight of the body shifts posteriorly to the articular processes. The nucleus may or may not press on a nerve root, as we know.

I have thought for many years, if we could possibly put a "jack" between the vertebral bodies and restore the height of the intervertebral space, restore the mechanics, we would probably be able to cure a great many of these patients. I think Dr. Harmon has that "jack." I think, by putting a graft between the intervertebral bodies, if he props them apart, he will cure many of these without ever having to worry about the intervertebral disc at all.

Arthur R. Metz (Chicago, Ill.): During the past fifteen years some of us have been very interested to hear the many papers and discussions concerning discs. To those of us who have been treating spinal complaints, including railroad spines for over thirty years, we often wonder how we ever got some of the patients back to work before the disc era.

For the past thirty-five years we have been treating our spinal complaints by means of firm massage and manipulation. By firm massage we mean massage given by men with strong hands who are able to do firm manipulation and stretching with the knees extended so as to loosen up the soft parts including adhesions about the nerves.

Before the disc era we got our patients back to work and are still getting them back to work with the same treatment.

I admit that some of our patients have their backs operated upon without my permission in other clinics, and almost never are we able to get those boys back to a job that requires their jumping on and off trains.

In the more severe, painful type of back commonly diagnosed as lumbago or sciatica it is sometimes necessary to do manipulation and stretching of the sciatic nerve under anesthesia and may be necessary to repeat several times in order to get results.

I myself can vouch for this treatment as I was the victim of such a severe sciatica (or disc) that it was necessary for me to be stretched under anesthesia on four occasions. With continued massage I made a complete recovery without any surgical interference. I personally will stay away

from the disc surgeon and also keep as many of my patients as possible out of their hands.

PAUL H. HARMON (closing): Dr. Metz's patients belong to an industry that is described as a "mature" industry, and most of the individuals employed in it, by the time they get to be railroad firemen and engineers, are in the arteriosclerotic and degenerative arthritic age group. I think that one should be extremely cautious about performing radical operations for degenerated intervertebral discs on persons over fifty years of age.

In our series, operated upon by the anterior extraperitoneal route, we had only one such patient who was an automobile mechanic by profession. Although he was not an industrial compensation case, he was one of the cases that tended to ruin the over-all appearance of this particular series of cases. It took him a year to get back to work and it was then necessary for him to accept a position with less pay because of disability elsewhere in the spine. He still has mild lumbar back pain. I believe this case was an error in selection. If one keeps out of the more advanced age groups, as represented by a good many of Dr. Metz's patients in the railroad industry, the results from operative treatment are better.

Conservative treatment, as outlined in the paper, should be tried first for all structural disabilities of the spine including degenerative disc disease. The time limitations for the termination of conservative treatment and the consideration of operative treatment are a matter of individual opinion. Even then, careful selection of patients from among the failures from conservative treatment should be practiced. In the entire series that we have reported, about 90 per cent of the patients were successfully treated by conservative means.

Murray Falkner has brought out the analogy of degenerative disc disease to degenerative disease of the medial meniscus of the knee. A good many persons over the age of twenty-five have degenerated intervertebral discs, but it is the exceptional patient who requires hospitalization for even conservative treatment, let alone a radical operation such as we have described.

A point that Dr. Dandy made in his writings was that there were few actual sequestrations of disc material lying free in the extradural space. It is a rare thing to find a disc fragment at operation that is completely detached and free in the neural canal with no roots in the annular centrum. Most degenerated discs that produce nerve root paresthesias are protruding partially sequestrated annulus fragments still covered with a variable thickness of the peripheral tough annulus fibers that blend with the longitudinal ligaments.

Dr. Voris' statement that nerve root compression was important should be emphasized but accepted at face value. Direct relief from the compression or nerve root stretching is obviously the aim at direct surgical treatment. However, such instances are rare. As mentioned above, paresthesias in most patients are produced by the annular bulge stretching the dural investment of the nerve root.

When we are confronted by patients who have definite neurologic findings, by which we refer to the more severe grades demonstrating muscle weakness and measurable atrophy or cases in which the myelogram shows a rounded defect indenting the dural shadow two-thirds or more, we recommend exploration by the posterior route.

Dr. Gilcreest asked about industrial cases. I have that correlation in one of the slides and it is in the paper. Unfortunately, although the number of cases operated upon by each method as described in the paper is about the same, the incidence of industrial compensation cases is not the same in each group. The cases in which fragmentary disc removal was done by the posterior route without spinal fusion were almost wholly industrial cases. Over 50 per cent of the industrial cases in this group received industrial settlement awards based chiefly upon subjective low back pain. In our group of cases, operated upon by the anterior route, there were only three industrial cases. Two of the three followed about the same course as the non-industrial cases, with prompt recovery and return to their former occupation. A third case required a year to return to work, received a disability award, but finally went back to work at a lighter occupation. Those that had the longest disability, irrespective of the type of operation performed, were the patients who were receiving industrial compensation.

FILMS SHOWN AT THE TENTH ANNUAL SESSION

The following were presented at the 1950 meeting of The American Association for the Surgery of Trauma:

Flexor Tendon Graft Technique—Walter C. Graham, Santa Barbara, California

Functional Repair of the Mandible Following Bone Loss from Injury, Irradiation Necrosis or Tumor—Donald M. Glover and Clifford L. Kiehn, Cleveland, Ohio

Excision of Lower Lumbar Intervertebral Discs—Paul H. Harmon, Oakland, California

Care and Rehabilitation of Spinal Cord Injuries—William G. Kuhn, New Brunswick, New Jersey

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The American Journal of Surgery

VOL. LXXX — Contents • December, 1950 — NUMBER SEVEN

Editorial

HEALING OF FRACTURES . . . . . *Edgar M. Bick* 843

Original Articles

SURGICAL TREATMENT OF CARDIOSPASM. . . . . *Maurice G. Buckles* 846

The symptom complex known as cardiospasm has been reviewed, the surgical procedures for its relief or cure have been described and five illustrative cases of cardiospasm subjected to surgery have been presented.

HEMANGIOMA OF THE COLON. . . . . *W. Wayne Babcock and Karl C. Jonas* 854

Hemangioma is considered the rarest type of tumor occurring in the large bowel. Herein is reported a sixth case added to the five already reported, with an enumeration of symptoms and treatment (details of operation and after-care).

SUBMUCOUS LIPOMA OF THE LARGE BOWEL. CASE REPORT WITH REVIEW OF THE LITERATURE *Harold N. Cavanaugh* 860

A case of a submucous lipoma of the large bowel is reported, with a review of the literature. A total of 152 cases of submucous lipoma have been reported.

CARCINOMA OF THE COLON. SELECTION OF THE OPERATIVE PROCEDURE . . . . . *Lester Breidenbach and Louis R. Slattery* 865

A general consideration of carcinoma of the colon and a review of ninety-nine consecutive resections of the colon for carcinoma from the standard point of selection of the operative procedure. Late results are not considered.

METHOD FOR RELIEVING IRREDUCIBLE INTUSSUSCEPTION . . . . *Kenneth C. Sawyer* 871

A description of an ingenious method of relieving an irreducible intussusception, thereby avoiding an operative procedure upon the intestine.

ISOLATED JEJUNAL INVOLVEMENT IN REGIONAL ENTERITIS . . . . . *John B. Gregg and Captain John R. Weisser* 873

A survey of the literature as pertains to jejunal involvement in regional enteritis is presented, with a report of eighty-four cases of jejunal lesions of which sixty-five were proved at operation or necropsy.

GELFOAM® AND THROMBIN IN TREATMENT OF MASSIVE GASTRODUODENAL HEMORRHAGE. A PRELIMINARY REPORT . . . . . *Meyer O. Cantor, Charles S. Kennedy and Roland P. Reynolds* 883

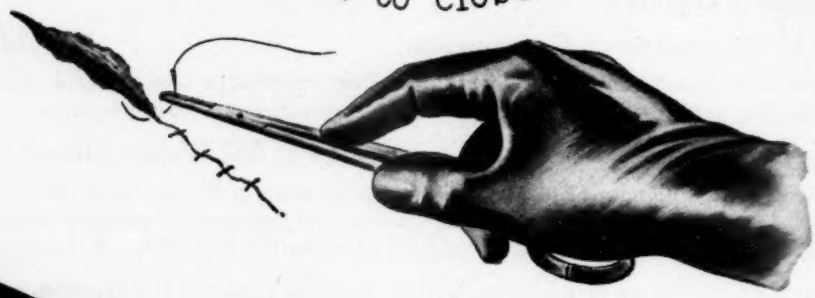
Report of twenty-seven consecutive patients with massive gastroduodenal hemorrhage treated with powdered gelfoam® and thrombin.

SPINA BIFIDA OCCULTA. A SURGICAL APPROACH . . . . . *John J. O'Connor, Jr. and Lieut. Caeser F. Orofino* 888

The authors point out the central nervous system disorder present in these cases of spina bifida occulta with peripheral symptoms. Three typical case reports are presented.

Contents Continued on Page 5

...from incision to closure...



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VOL. LXXX — Contents • December, 1950 — NUMBER SEVEN

SIMULTANEOUS FEMORAL HEAD FRACTURE AND TRAUMATIC HIP DISLOCATION. *Joe B. Davis* 893

The author is of the opinion that concurrent femoral head fracture and traumatic hip dislocation is more common than generally believed. The treatment is described and aftercare given.

CYSTOSARCOMATOID PHYLLODES . . . . . *Charles E. Horton and James M. Baker* 896

A case of cystosarcoma phyllodes is presented and a modification of the historic name to cystosarcomatoid phyllodes is proposed. The signs, symptoms, prognosis and pathologic findings of this tumor are reviewed.

FRACTURES OF BOTH BONES OF THE FOREARM. *Hugh A. Thompson and Alfred T. Hamilton* 899

The authors present a satisfactory method of treating fractures of both bones of the forearm thus making it possible to avoid in almost all cases the necessity of open operation.

PARAVESICAL EXTRAPERITONEAL CESAREAN SECTION TECHNIC. . . . . *James Francis Norton and Edith Mangone* 902

The authors contend that all labors complicated by the presence of potential infection of the amniotic sac demand as a universal minimum antibiotic and sulfonamide therapy prophylactically throughout the entire labor, sufficient parenteral fluid, proper and adequate sedation, and if the labor must be terminated by the abdominal approach, the utilization of an extraperitoneal cesarean section. The technic of paravesical extraperitoneal cesarean section is described.

ARTHRODESIS OF THE HIP . . . . . *Duncan C. McKeever* 906

A technic is described for arthrodesis of the hip which the author believes makes it a less formidable and more certain procedure, and extends the age limit at which it can be justifiably attempted. This procedure has been carried out in five cases.

INNER TABLE OF ANTERIOR ILIUM, A CONVENIENT BONE DONOR SITE FOR GRAFTING . . *Frederick R. Thompson* 907

A technic is given for grafting utilizing the inner table of the anterior ilium, a convenient bone donor site.

Modern Operative Technics

RECENT IMPROVEMENTS IN RESECTION OF THE MAXILLA . . . . . *G. E. Ward and Milton Edgerton, Jr.* 909

A technic is given for resection of the upper jaw and related structures which need no longer carry a high operative mortality. The authors tell when to do plastic repair and so greatly reduce the deformity and discomfort. Use of the modern "hollow-ball" type of acrylic prosthesis will further complement this result and improve speech.

Practical Surgical Suggestions

TOURNIQUET FOR INTRAVENOUS THERAPY FOR PATIENTS IN SHOCK . . . *Norman Ende* 915

INTRAGASTRIC TAMPONADE FOR INTRACTABLE ESOPHAGEAL, GASTRIC OR DUODENAL BLEEDING. . . . . *H. B. Benjamin* 917

Contents Continued on Page 7

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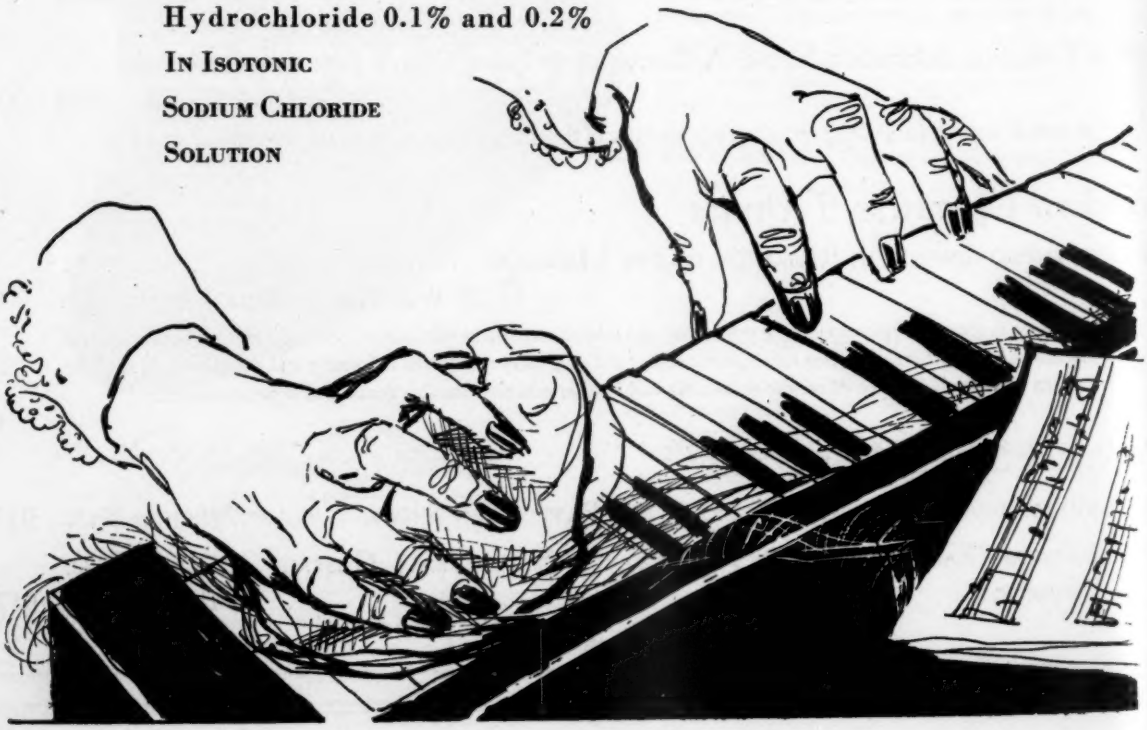
1. Graubard, D. J., and Peterson, M. C. (1949), Intravenous Use of Procaine in the Management of Arthritis, J. Amer. Med. Assn., 141:756, Nov. 12.



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Reg. U. S. Pat. Off., Nov. 3, 1936

VOL. LXXX — Contents • December, 1950 — NUMBER SEVEN

Case Reports

SUBMUCOUS LIPOMAS OF THE SMALL INTESTINE . *Franklin R. Smith and Charles W. Mayo* 922

A report of an unusual case which serves to focus attention on the place of benign tumors in the differential diagnosis of intestinal obstruction, unexplained melena and epigastric distress.

EPIDERMAL FISTULA OF THE PERINEUM . . . . *Monte Edwards and D. L. Reimann* 929

The significance of epidermal fistula of the perineum lies in the diagnosis—the differentiation from true anal fistula, pilonidal sinus and from any epithelium-lined sinus having its origin in the anal canal. Illustrative case reports with the treatment are outlined.

CHORIO-EPITHELIOMA FOLLOWING HYSTERECTOMY . *George Willeford and R. H. Rigdon* 933

The report of a case in which death occurred from a metastatic chorio-epithelioma seven years following hysterectomy.

PRIMARY MESENTERIC THROMBOSIS TREATED WITH RESECTION AND ANTICOAGULANTS . . *Paul A. Knepper, John R. McDaniel, Robert M. Brooker and Louis G. Neudorff* 937

About 611 cases of mesenteric vascular occlusion have been reported. Of these, fifty-three patients have recovered and eighteen of these recoveries have been reported in the last four years. The authors tell why today an increasing number of these patients recover. Two new successfully treated cases are reported.

BENIGN STRICTURE OF THE COMMON BILE DUCT. . . . . *Harwell Wilson* 941

Stricture of the common bile duct is often due to operative trauma. Inflammatory processes occasionally may result in a stricture. The difficult situations encountered during biliary tract surgery are pointed out together with surgical technics most helpful in avoiding operative injury. The value of partial hepatectomy and intrahepatic cholangiojejunostomy in difficult cases is discussed and a case utilizing this method reviewed.

DUODENAL DIVERTICULA . . . . . .*Claude C. Blackwell* 946

A review of the literature of duodenal diverticula is presented. The incidence, etiology, pathology, location and symptomatology are discussed, the surgical management is outlined and a case report of a patient successfully operated upon is presented.

PRIMARY SARCOMA OF THE GREATER OMENTUM . . . . . *William C. Cantey, F. Eugene Zemp and Ralph T. McCauley* 954

The ninety-third recorded case of sarcoma of the greater omentum is presented. The diagnosis was made at operation. There is a brief review of the literature.

COCCIDIOIDOMYCOSIS OF FEMALE ADNEXA . . . . . *Lowell C. Wormley, Lazarus Manoil and Maurice Rosenthal* 958

The author believes this is the third case reported of coccidioidomycosis of the female adnexa. The epidemiology, pathogenesis and diagnosis are reviewed.

RETROPERITONEAL TERATOMA . . . . . *A. J. Anlyan and P. V. Harper* 961

The clinical history and detailed pathologic discussion is presented of a five month old female from whom a retroperitoneal teratoma was successfully removed.

AUTHOR INDEX TO VOLUME LXXX. 965

SUBJECT INDEX TO VOLUME LXXX. 967

Advertising Index on 3rd Cover

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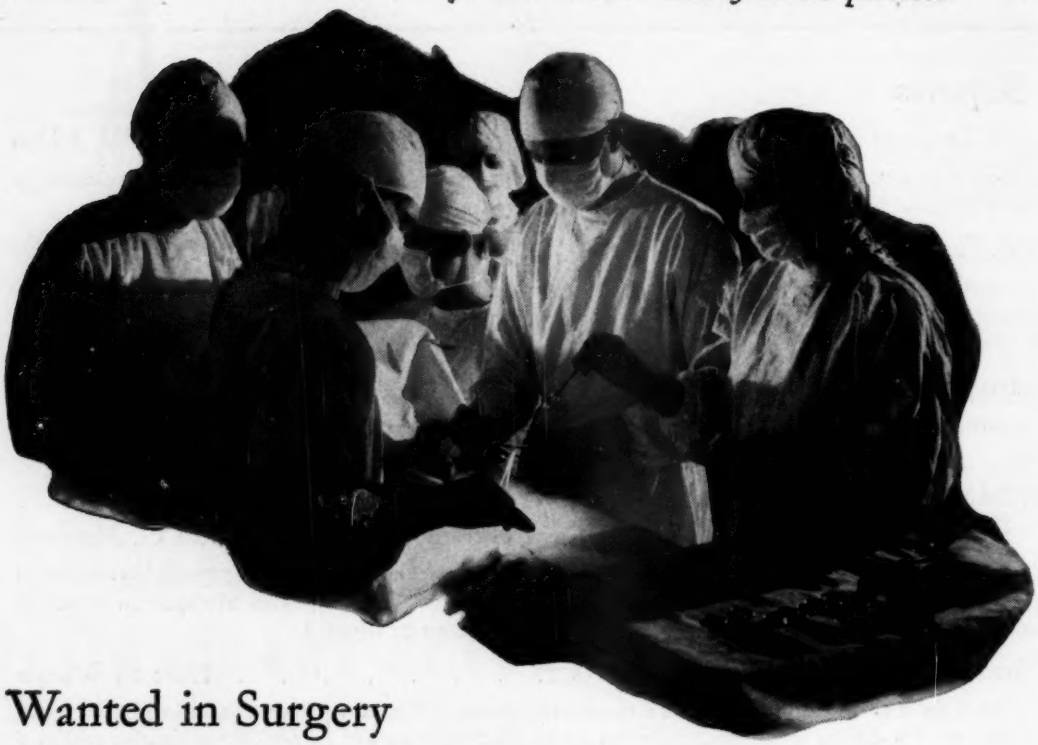

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